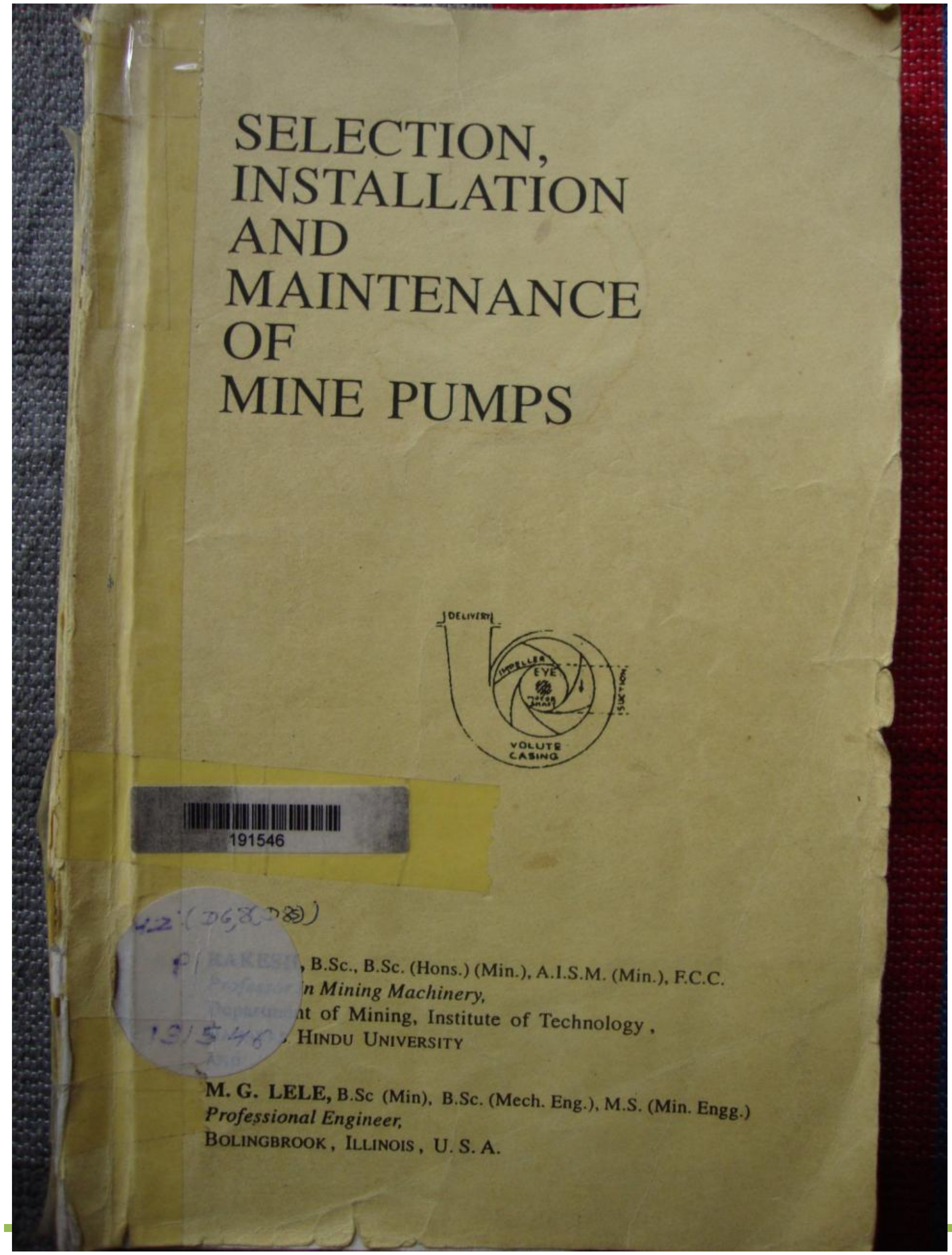

DELIVERY
IMPELLER
EYE
MOTOR SHAFT
SUCTION
VOLUTE CASING

SELECTION, INSTALLATION AND MAINTENANCE OF MINE PUMPS

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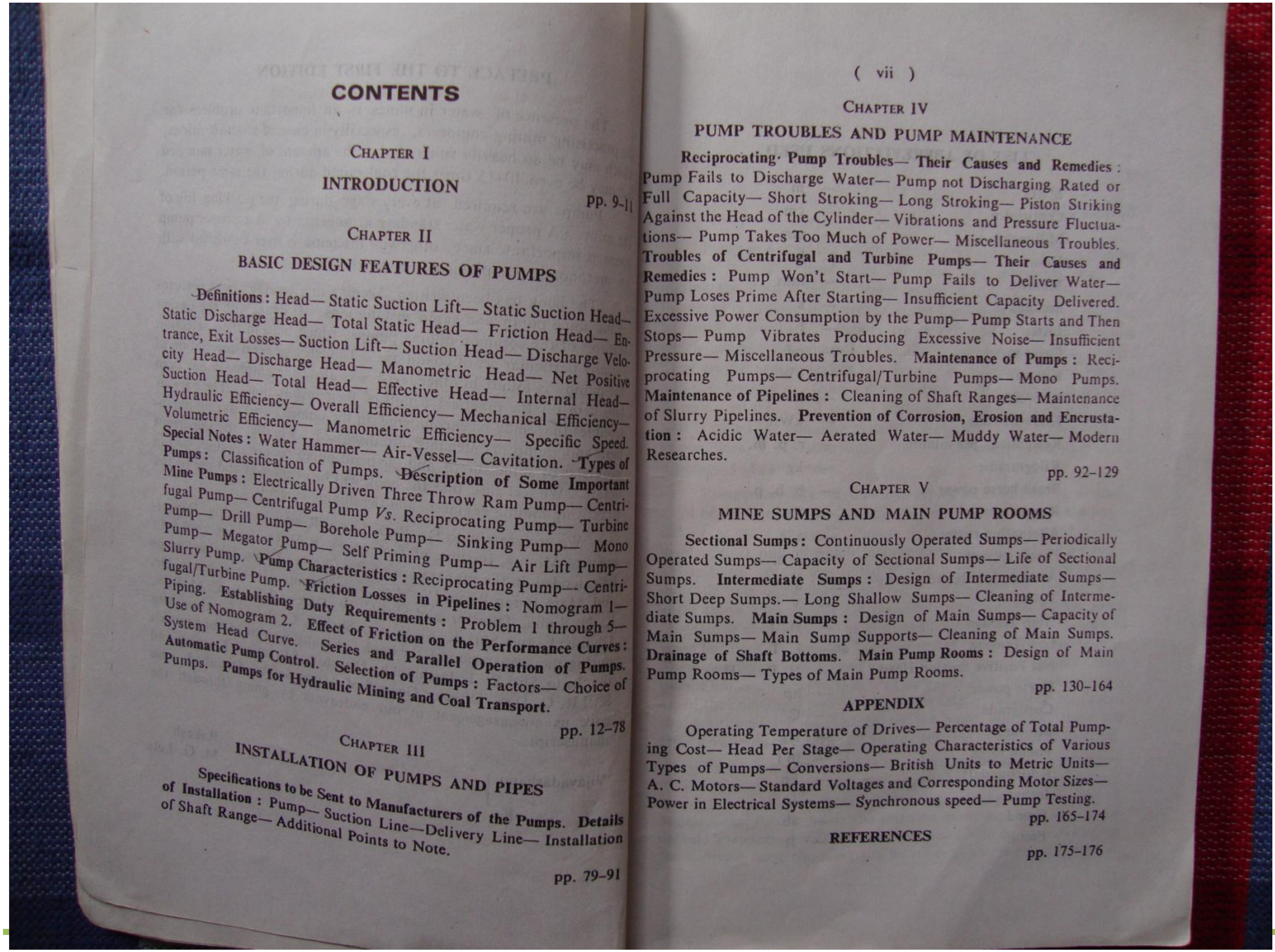

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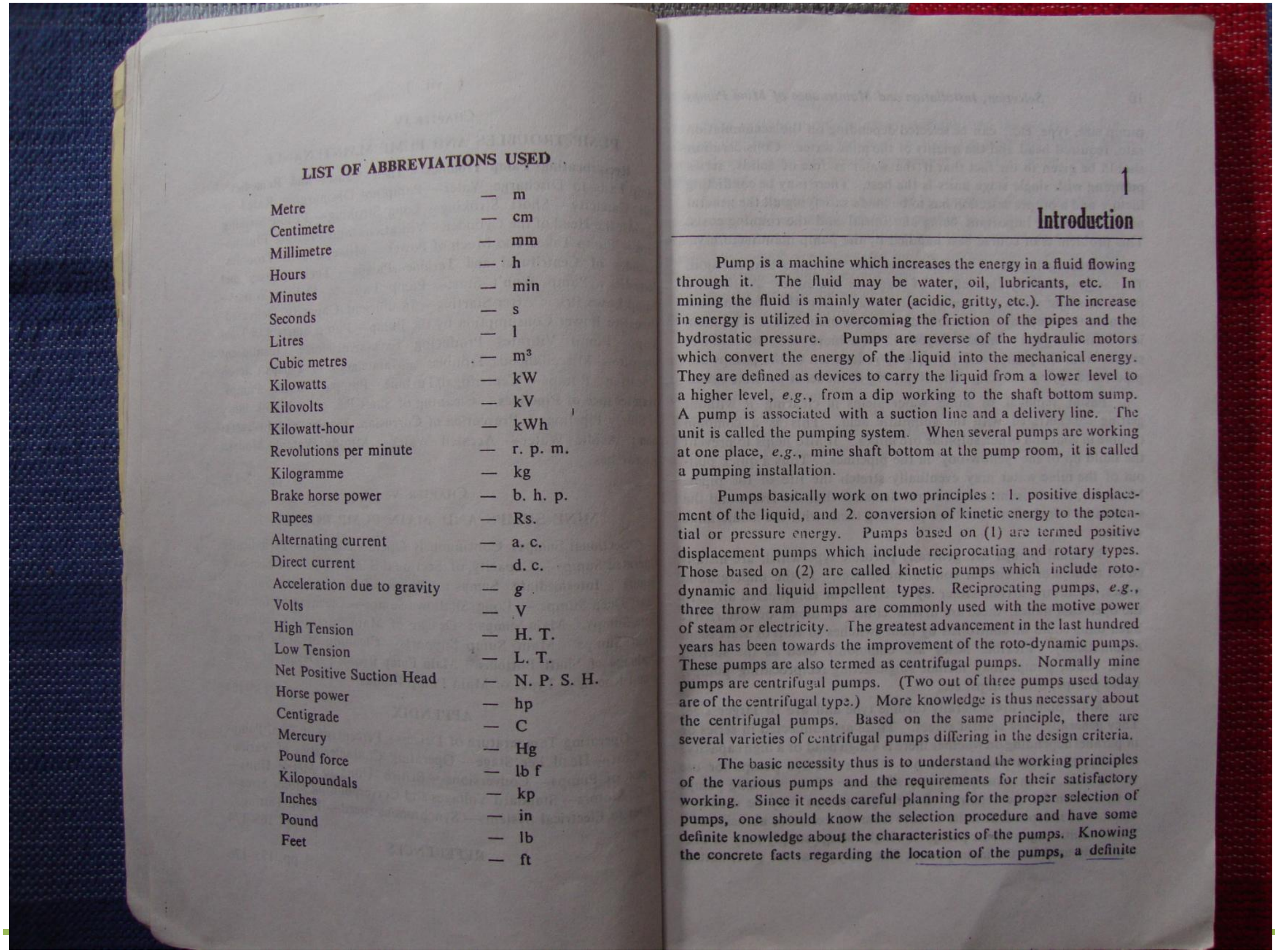


LIST OF ABBREVIATIONS USED

Metre — m
Centimetre — cm
Millimetre — mm
Hours — h
Minutes — min
Seconds — s
Litres — l
Cubic metres — m^3
Kilowatts — kW
Kilovolts — kV
Kilowatt-hour — kWh
Revolutions per minute — r. p. m.
Kilogramme — kg
Brake horse power — b. h. p.
Rupees — Rs.
Alternating current — a. c.
Direct current — d. c.
Acceleration due to gravity — g
Volts — V
High Tension — H. T.
Low Tension — L. T.
Net Positive Suction Head — N. P. S. H.
Horse power — hp
Centigrade — C
Mercury — Hg
Pound force — lb f
Kilopoundals — kp
Inches — in
Pound — lb
Feet — ft

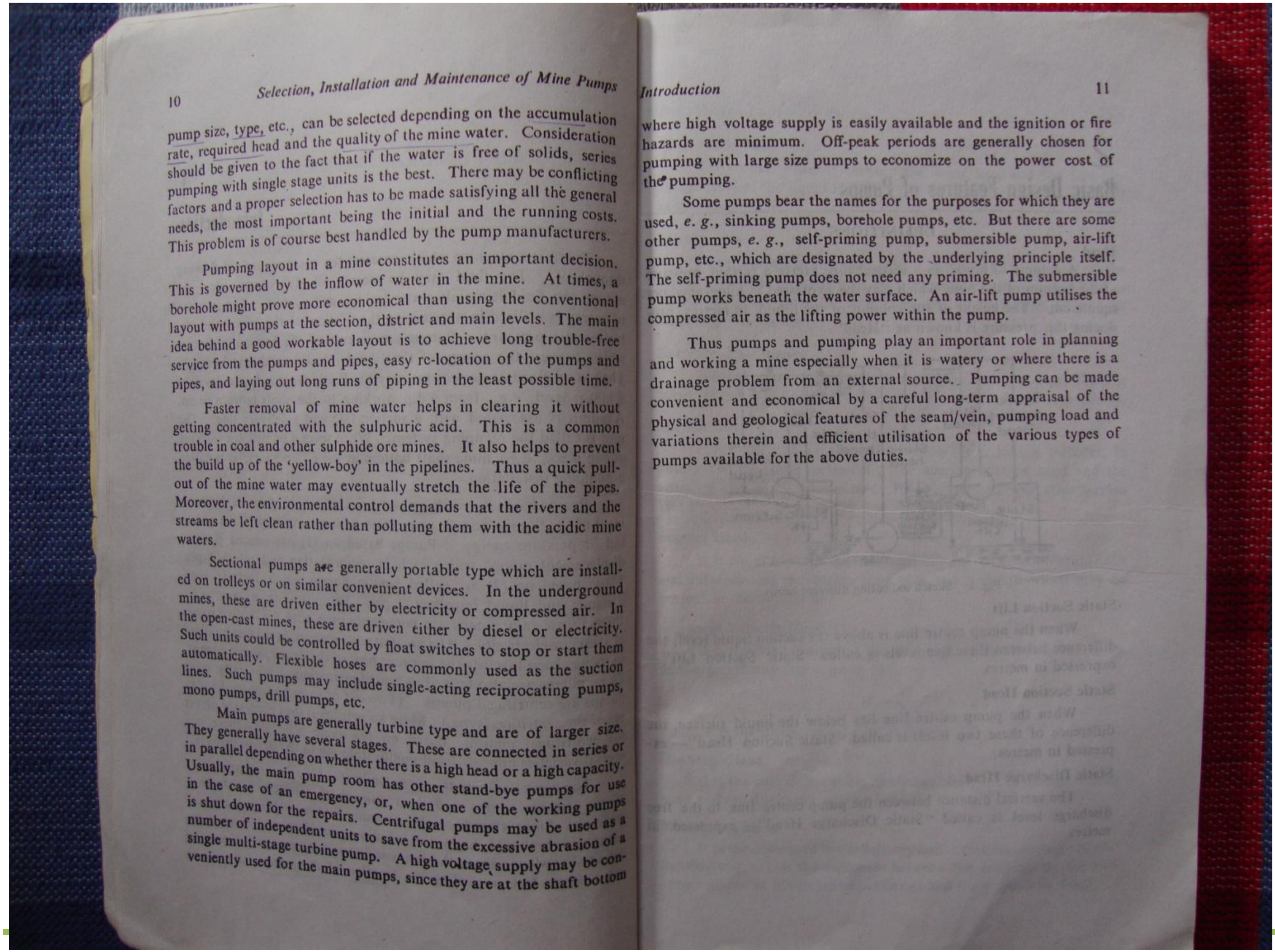
1

Introduction

Pump is a machine which increases the energy in a fluid flowing through it. The fluid may be water, oil, lubricants, etc. In mining the fluid is mainly water (acidic, gritty, etc.). The increase in energy is utilized in overcoming the friction of the pipes and the hydrostatic pressure. Pumps are reverse of the hydraulic motors which convert the energy of the liquid into the mechanical energy. They are defined as devices to carry the liquid from a lower level to a higher level, *e.g.*, from a dip working to the shaft bottom sump. A pump is associated with a suction line and a delivery line. The unit is called the pumping system. When several pumps are working at one place, *e.g.*, mine shaft bottom at the pump room, it is called a pumping installation.

Pumps basically work on two principles : 1. positive displacement of the liquid, and 2. conversion of kinetic energy to the potential or pressure energy. Pumps based on (1) are termed positive displacement pumps which include reciprocating and rotary types. Those based on (2) are called kinetic pumps which include roto-dynamic and liquid impellent types. Reciprocating pumps, *e.g.*, three throw ram pumps are commonly used with the motive power of steam or electricity. The greatest advancement in the last hundred years has been towards the improvement of the roto-dynamic pumps. These pumps are also termed as centrifugal pumps. Normally mine pumps are centrifugal pumps. (Two out of three pumps used today are of the centrifugal type.) More knowledge is thus necessary about the centrifugal pumps. Based on the same principle, there are several varieties of centrifugal pumps differing in the design criteria.

The basic necessity thus is to understand the working principles of the various pumps and the requirements for their satisfactory working. Since it needs careful planning for the proper selection of pumps, one should know the selection procedure and have some definite knowledge about the characteristics of the pumps. Knowing the concrete facts regarding the location of the pumps, a definite



pump size, type, etc., can be selected depending on the accumulation rate, required head and the quality of the mine water. Consideration should be given to the fact that if the water is free of solids, series pumping with single stage units is the best. There may be conflicting factors and a proper selection has to be made satisfying all the general needs, the most important being the initial and the running costs. This problem is of course best handled by the pump manufacturers.

Pumping layout in a mine constitutes an important decision. This is governed by the inflow of water in the mine. At times, a borehole might prove more economical than using the conventional layout with pumps at the section, district and main levels. The main idea behind a good workable layout is to achieve long trouble-free service from the pumps and pipes, easy re-location of the pumps and pipes, and laying out long runs of piping in the least possible time.

Faster removal of mine water helps in clearing it without getting concentrated with the sulphuric acid. This is a common trouble in coal and other sulphide ore mines. It also helps to prevent the build up of the 'yellow-boy' in the pipelines. Thus a quick pull-out of the mine water may eventually stretch the life of the pipes. Moreover, the environmental control demands that the rivers and the streams be left clean rather than polluting them with the acidic mine waters.

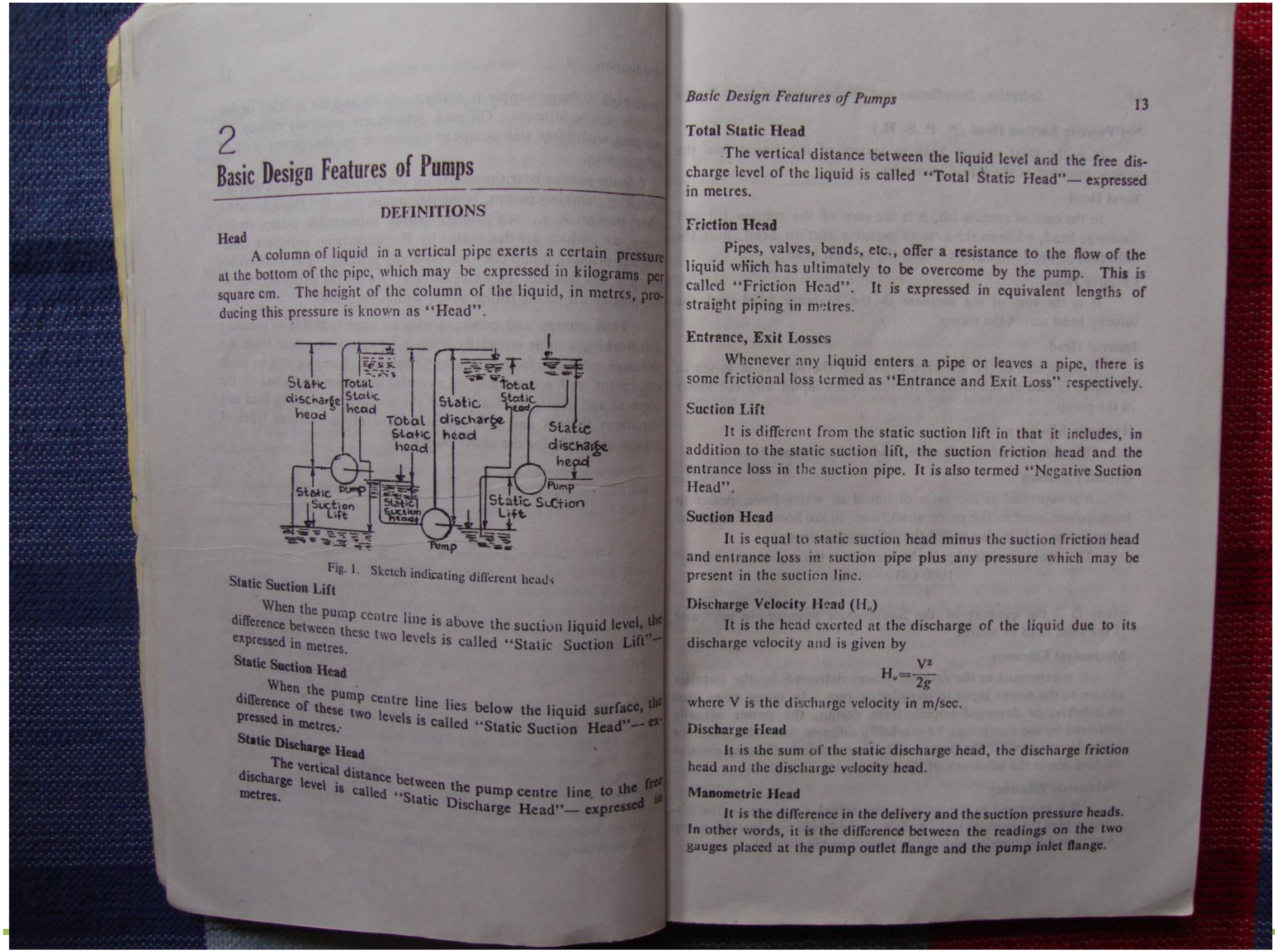
Sectional pumps are generally portable type which are installed on trolleys or on similar convenient devices. In the underground mines, these are driven either by electricity or compressed air. In the open-cast mines, these are driven either by diesel or electricity. Such units could be controlled by float switches to stop or start them automatically. Flexible hoses are commonly used as the suction lines. Such pumps may include single-acting reciprocating pumps, mono pumps, drill pumps, etc.

Main pumps are generally turbine type and are of larger size. They generally have several stages. These are connected in series or in parallel depending on whether there is a high head or a high capacity. Usually, the main pump room has other stand-bye pumps for use in the case of an emergency, or, when one of the working pumps is shut down for the repairs. Centrifugal pumps may be used as a number of independent units to save from the excessive abrasion of a single multi-stage turbine pump. A high voltage supply may be conveniently used for the main pumps, since they are at the shaft bottom

where high voltage supply is easily available and the ignition or fire hazards are minimum. Off-peak periods are generally chosen for pumping with large size pumps to economize on the power cost of the pumping.

Some pumps bear the names for the purposes for which they are used, *e. g.*, sinking pumps, borehole pumps, etc. But there are some other pumps, *e. g.*, self-priming pump, submersible pump, air-lift pump, etc., which are designated by the underlying principle itself. The self-priming pump does not need any priming. The submersible pump works beneath the water surface. An air-lift pump utilises the compressed air as the lifting power within the pump.

Thus pumps and pumping play an important role in planning and working a mine especially when it is watery or where there is a drainage problem from an external source. Pumping can be made convenient and economical by a careful long-term appraisal of the physical and geological features of the seam/vein, pumping load and variations therein and efficient utilisation of the various types of pumps available for the above duties.


Static discharge head
Total Static head
Static Suction Lift
Pump
Total Static head
Static Suction heads
Static discharge head
Pump
Total Static head
Static discharge head
Pump
Static Suction Lift

2

Basic Design Features of Pumps

DEFINITIONS

Head

A column of liquid in a vertical pipe exerts a certain pressure at the bottom of the pipe, which may be expressed in kilograms per square cm. The height of the column of the liquid, in metres, producing this pressure is known as "Head".

Fig. 1. Sketch indicating different heads

Static Suction Lift

When the pump centre line is above the suction liquid level, the difference between these two levels is called "Static Suction Lift"— expressed in metres.

Static Suction Head

When the pump centre line lies below the liquid surface, the difference of these two levels is called "Static Suction Head"— expressed in metres.

Static Discharge Head

The vertical distance between the pump centre line to the free discharge level is called "Static Discharge Head"— expressed in metres.

Total Static Head

The vertical distance between the liquid level and the free discharge level of the liquid is called "Total Static Head"— expressed in metres.

Friction Head

Pipes, valves, bends, etc., offer a resistance to the flow of the liquid which has ultimately to be overcome by the pump. This is called "Friction Head". It is expressed in equivalent lengths of straight piping in metres.

Entrance, Exit Losses

Whenever any liquid enters a pipe or leaves a pipe, there is some frictional loss termed as "Entrance and Exit Loss" respectively.

Suction Lift

It is different from the static suction lift in that it includes, in addition to the static suction lift, the suction friction head and the entrance loss in the suction pipe. It is also termed "Negative Suction Head".

Suction Head

It is equal to static suction head minus the suction friction head and entrance loss in suction pipe plus any pressure which may be present in the suction line.

Discharge Velocity Head (H_v)

It is the head exerted at the discharge of the liquid due to its discharge velocity and is given by

$$H_v = \frac{V^2}{2g}$$

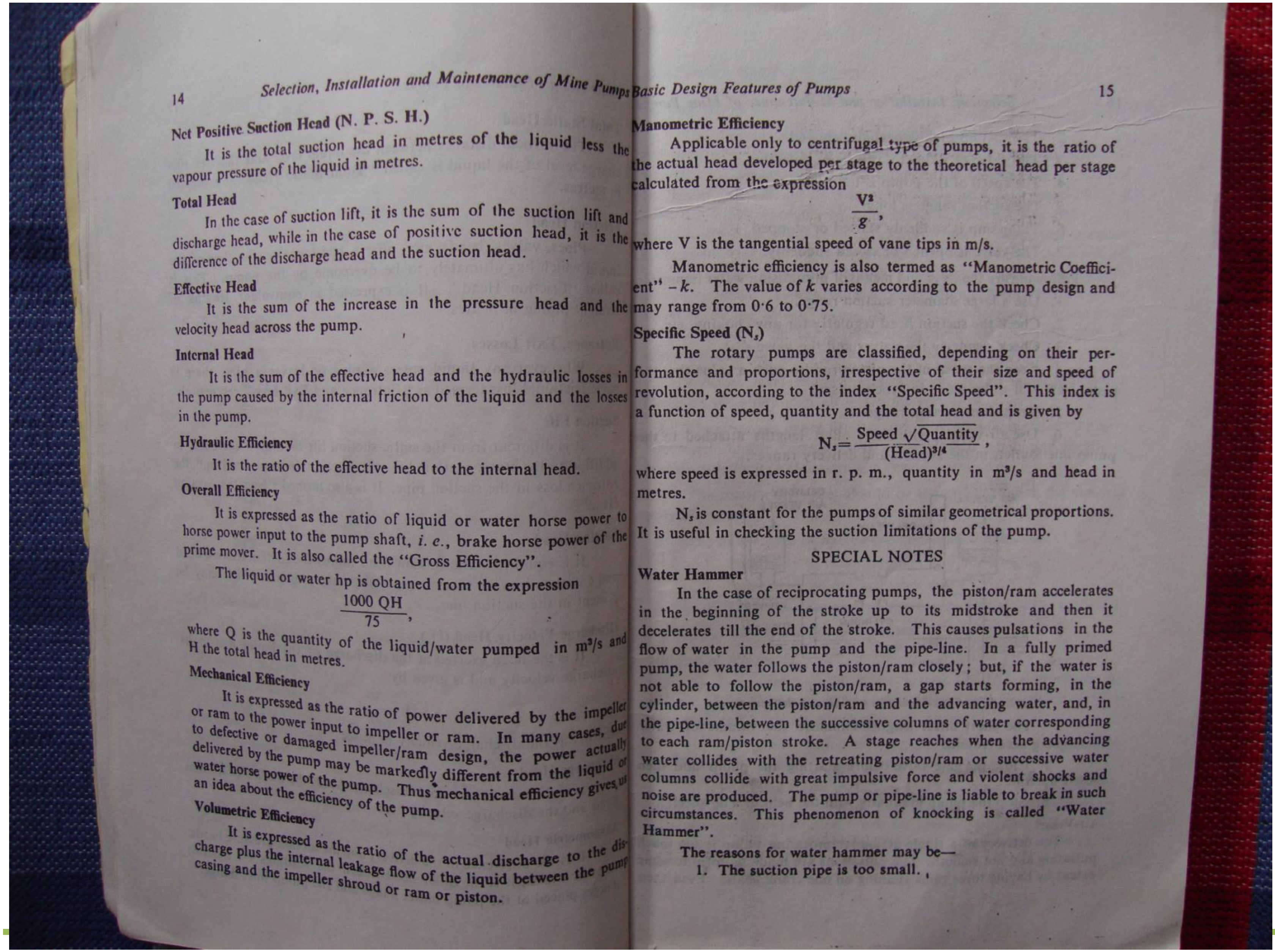
where V is the discharge velocity in m/sec.

Discharge Head

It is the sum of the static discharge head, the discharge friction head and the discharge velocity head.

Manometric Head

It is the difference in the delivery and the suction pressure heads. In other words, it is the difference between the readings on the two gauges placed at the pump outlet flange and the pump inlet flange.



Net Positive Suction Head (N. P. S. H.)

It is the total suction head in metres of the liquid less the vapour pressure of the liquid in metres.

Total Head

In the case of suction lift, it is the sum of the suction lift and discharge head, while in the case of positive suction head, it is the difference of the discharge head and the suction head.

Effective Head

It is the sum of the increase in the pressure head and the velocity head across the pump.

Internal Head

It is the sum of the effective head and the hydraulic losses in the pump caused by the internal friction of the liquid and the losses in the pump.

Hydraulic Efficiency

It is the ratio of the effective head to the internal head.

Overall Efficiency

It is expressed as the ratio of liquid or water horse power to horse power input to the pump shaft, *i. e.*, brake horse power of the prime mover. It is also called the "Gross Efficiency".

The liquid or water hp is obtained from the expression

$$\frac{1000\,QH}{75},$$

where Q is the quantity of the liquid/water pumped in m^3/s and H the total head in metres.

Mechanical Efficiency

It is expressed as the ratio of power delivered by the impeller or ram to the power input to impeller or ram. In many cases, due to defective or damaged impeller/ram design, the power actually delivered by the pump may be markedly different from the liquid or water horse power of the pump. Thus mechanical efficiency gives us an idea about the efficiency of the pump.

Volumetric Efficiency

It is expressed as the ratio of the actual discharge to the discharge plus the internal leakage flow of the liquid between the pump casing and the impeller shroud or ram or piston.

Manometric Efficiency

Applicable only to centrifugal type of pumps, it is the ratio of the actual head developed per stage to the theoretical head per stage calculated from the expression

$$\frac{V^2}{g},$$

where V is the tangential speed of vane tips in m/s.

Manometric efficiency is also termed as "Manometric Coefficient" $-k$. The value of k varies according to the pump design and may range from 0·6 to 0·75.

Specific Speed (N_s)

The rotary pumps are classified, depending on their performance and proportions, irrespective of their size and speed of revolution, according to the index "Specific Speed". This index is a function of speed, quantity and the total head and is given by

$$N_s = \frac{\text{Speed}\ \sqrt{\text{Quantity}}}{(\text{Head})^{3/4}},$$

where speed is expressed in r. p. m., quantity in m^3/s and head in metres.

N_s is constant for the pumps of similar geometrical proportions. It is useful in checking the suction limitations of the pump.

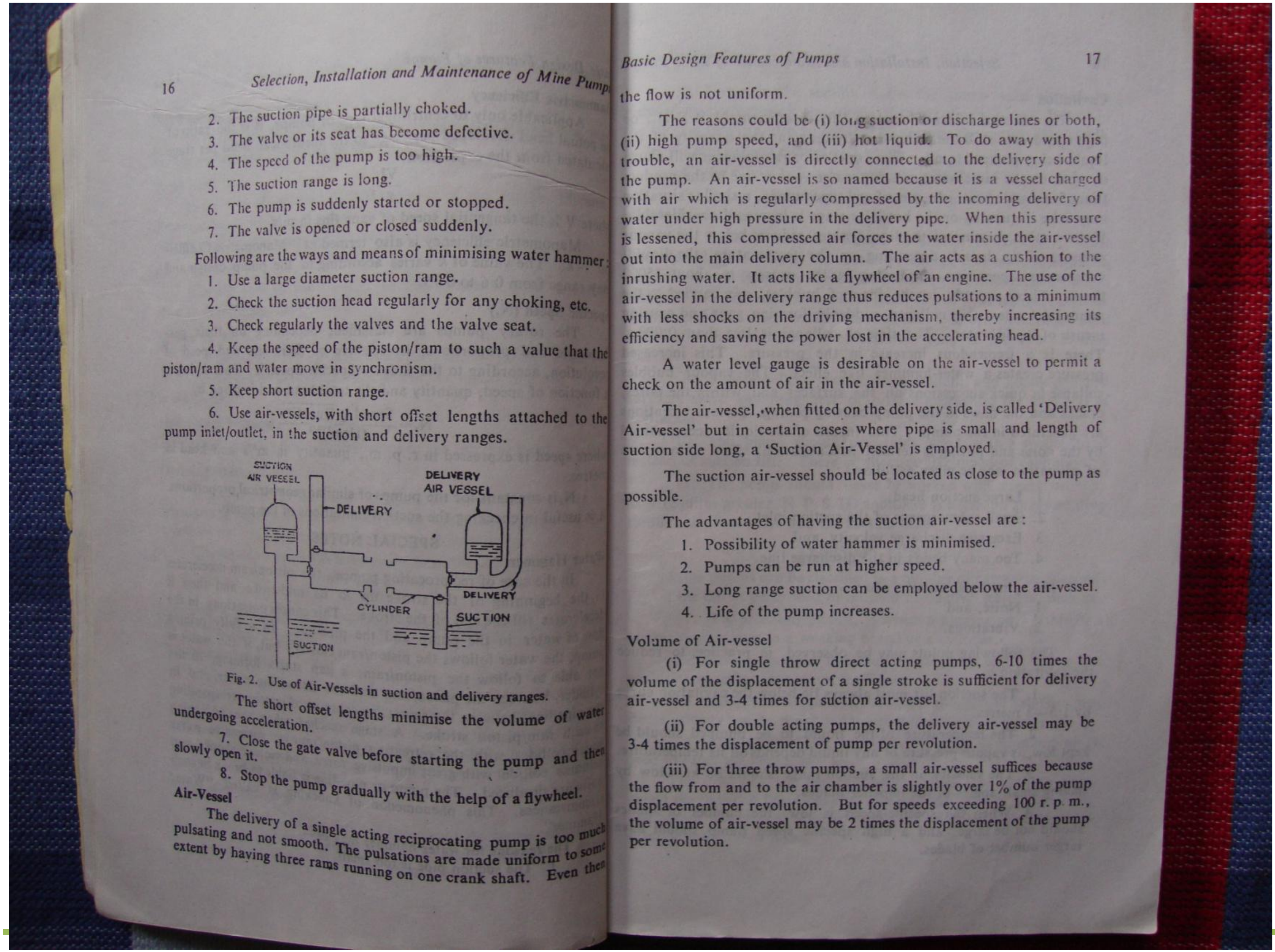
SPECIAL NOTES

Water Hammer

In the case of reciprocating pumps, the piston/ram accelerates in the beginning of the stroke up to its midstroke and then it decelerates till the end of the stroke. This causes pulsations in the flow of water in the pump and the pipe-line. In a fully primed pump, the water follows the piston/ram closely; but, if the water is not able to follow the piston/ram, a gap starts forming, in the cylinder, between the piston/ram and the advancing water, and, in the pipe-line, between the successive columns of water corresponding to each ram/piston stroke. A stage reaches when the advancing water collides with the retreating piston/ram or successive water columns collide with great impulsive force and violent shocks and noise are produced. The pump or pipe-line is liable to break in such circumstances. This phenomenon of knocking is called "Water Hammer".

The reasons for water hammer may be—

1. The suction pipe is too small.



2. The suction pipe is partially choked.
3. The valve or its seat has become defective.
4. The speed of the pump is too high.
5. The suction range is long.
6. The pump is suddenly started or stopped.
7. The valve is opened or closed suddenly.

Following are the ways and means of minimising water hammer:

1. Use a large diameter suction range.
2. Check the suction head regularly for any choking, etc.
3. Check regularly the valves and the valve seat.
4. Keep the speed of the piston/ram to such a value that the piston/ram and water move in synchronism.
5. Keep short suction range.
6. Use air-vessels, with short offset lengths attached to the pump inlet/outlet, in the suction and delivery ranges.

Fig. 2. Use of Air-Vessels in suction and delivery ranges.

The short offset lengths minimise the volume of wate undergoing acceleration.

7. Close the gate valve before starting the pump and the slowly open it.

8. Stop the pump gradually with the help of a flywheel.

Air-Vessel

The delivery of a single acting reciprocating pump is too muc pulsating and not smooth. The pulsations are made uniform to som extent by having three rams running on one crank shaft. Even the

the flow is not uniform.

The reasons could be (i) long suction or discharge lines or both, (ii) high pump speed, and (iii) hot liquid. To do away with this trouble, an air-vessel is directly connected to the delivery side of the pump. An air-vessel is so named because it is a vessel charged with air which is regularly compressed by the incoming delivery of water under high pressure in the delivery pipe. When this pressure is lessened, this compressed air forces the water inside the air-vessel out into the main delivery column. The air acts as a cushion to the inrushing water. It acts like a flywheel of an engine. The use of the air-vessel in the delivery range thus reduces pulsations to a minimum with less shocks on the driving mechanism, thereby increasing its efficiency and saving the power lost in the accelerating head.

A water level gauge is desirable on the air-vessel to permit a check on the amount of air in the air-vessel.

The air-vessel, when fitted on the delivery side, is called 'Delivery Air-vessel' but in certain cases where pipe is small and length of suction side long, a 'Suction Air-Vessel' is employed.

The suction air-vessel should be located as close to the pump as possible.

The advantages of having the suction air-vessel are:

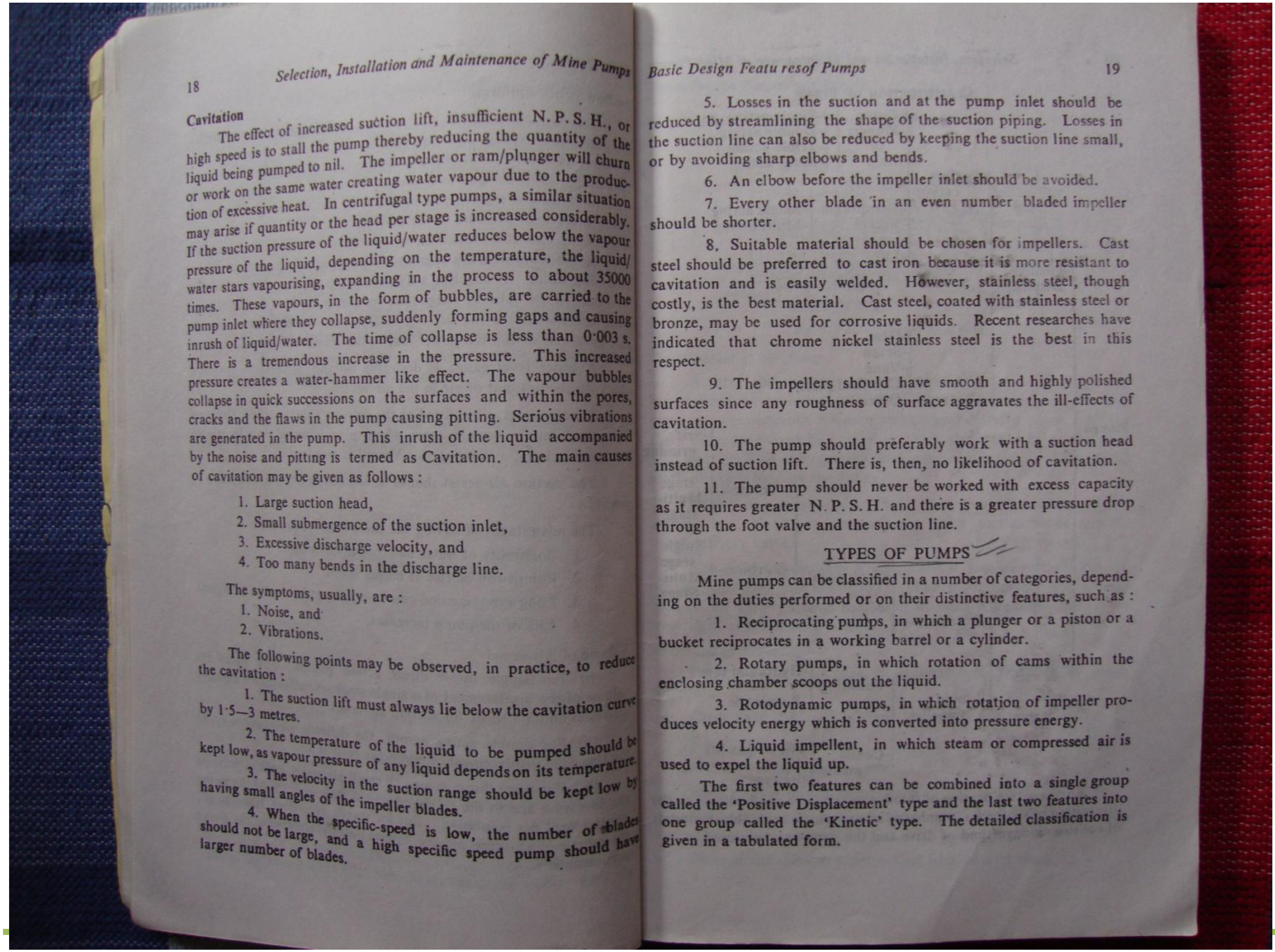
1. Possibility of water hammer is minimised.
2. Pumps can be run at higher speed.
3. Long range suction can be employed below the air-vessel.
4. Life of the pump increases.

Volume of Air-vessel

(i) For single throw direct acting pumps, 6-10 times the volume of the displacement of a single stroke is sufficient for delivery air-vessel and 3-4 times for suction air-vessel.

(ii) For double acting pumps, the delivery air-vessel may be 3-4 times the displacement of pump per revolution.

(iii) For three throw pumps, a small air-vessel suffices because the flow from and to the air chamber is slightly over 1% of the pump displacement per revolution. But for speeds exceeding 100 r. p. m., the volume of air-vessel may be 2 times the displacement of the pump per revolution.



18 *Selection, Installation and Maintenance of Mine Pumps*

Cavitation

The effect of increased suction lift, insufficient N. P. S. H., or high speed is to stall the pump thereby reducing the quantity of the liquid being pumped to nil. The impeller or ram/plunger will churn or work on the same water creating water vapour due to the production of excessive heat. In centrifugal type pumps, a similar situation may arise if quantity or the head per stage is increased considerably. If the suction pressure of the liquid/water reduces below the vapour pressure of the liquid, depending on the temperature, the liquid/water stars vapourising, expanding in the process to about 35000 times. These vapours, in the form of bubbles, are carried to the pump inlet where they collapse, suddenly forming gaps and causing inrush of liquid/water. The time of collapse is less than 0·003 s. There is a tremendous increase in the pressure. This increased pressure creates a water-hammer like effect. The vapour bubbles collapse in quick successions on the surfaces and within the pores, cracks and the flaws in the pump causing pitting. Serious vibrations are generated in the pump. This inrush of the liquid accompanied by the noise and pitting is termed as Cavitation. The main causes of cavitation may be given as follows :

1. Large suction head,
2. Small submergence of the suction inlet,
3. Excessive discharge velocity, and
4. Too many bends in the discharge line.

The symptoms, usually, are :

1. Noise, and
2. Vibrations.

The following points may be observed, in practice, to reduce the cavitation :

1. The suction lift must always lie below the cavitation curve by 1·5—3 metres.

2. The temperature of the liquid to be pumped should be kept low, as vapour pressure of any liquid depends on its temperature.

3. The velocity in the suction range should be kept low by having small angles of the impeller blades.

4. When the specific-speed is low, the number of blades should not be large, and a high specific speed pump should have larger number of blades.

Basic Design Featu resof Pumps 19

5. Losses in the suction and at the pump inlet should be reduced by streamlining the shape of the suction piping. Losses in the suction line can also be reduced by keeping the suction line small, or by avoiding sharp elbows and bends.

6. An elbow before the impeller inlet should be avoided.

7. Every other blade in an even number bladed impeller should be shorter.

8. Suitable material should be chosen for impellers. Cast steel should be preferred to cast iron because it is more resistant to cavitation and is easily welded. However, stainless steel, though costly, is the best material. Cast steel, coated with stainless steel or bronze, may be used for corrosive liquids. Recent researches have indicated that chrome nickel stainless steel is the best in this respect.

9. The impellers should have smooth and highly polished surfaces since any roughness of surface aggravates the ill-effects of cavitation.

10. The pump should preferably work with a suction head instead of suction lift. There is, then, no likelihood of cavitation.

11. The pump should never be worked with excess capacity as it requires greater N. P. S. H. and there is a greater pressure drop through the foot valve and the suction line.

TYPES OF PUMPS

Mine pumps can be classified in a number of categories, depending on the duties performed or on their distinctive features, such as :

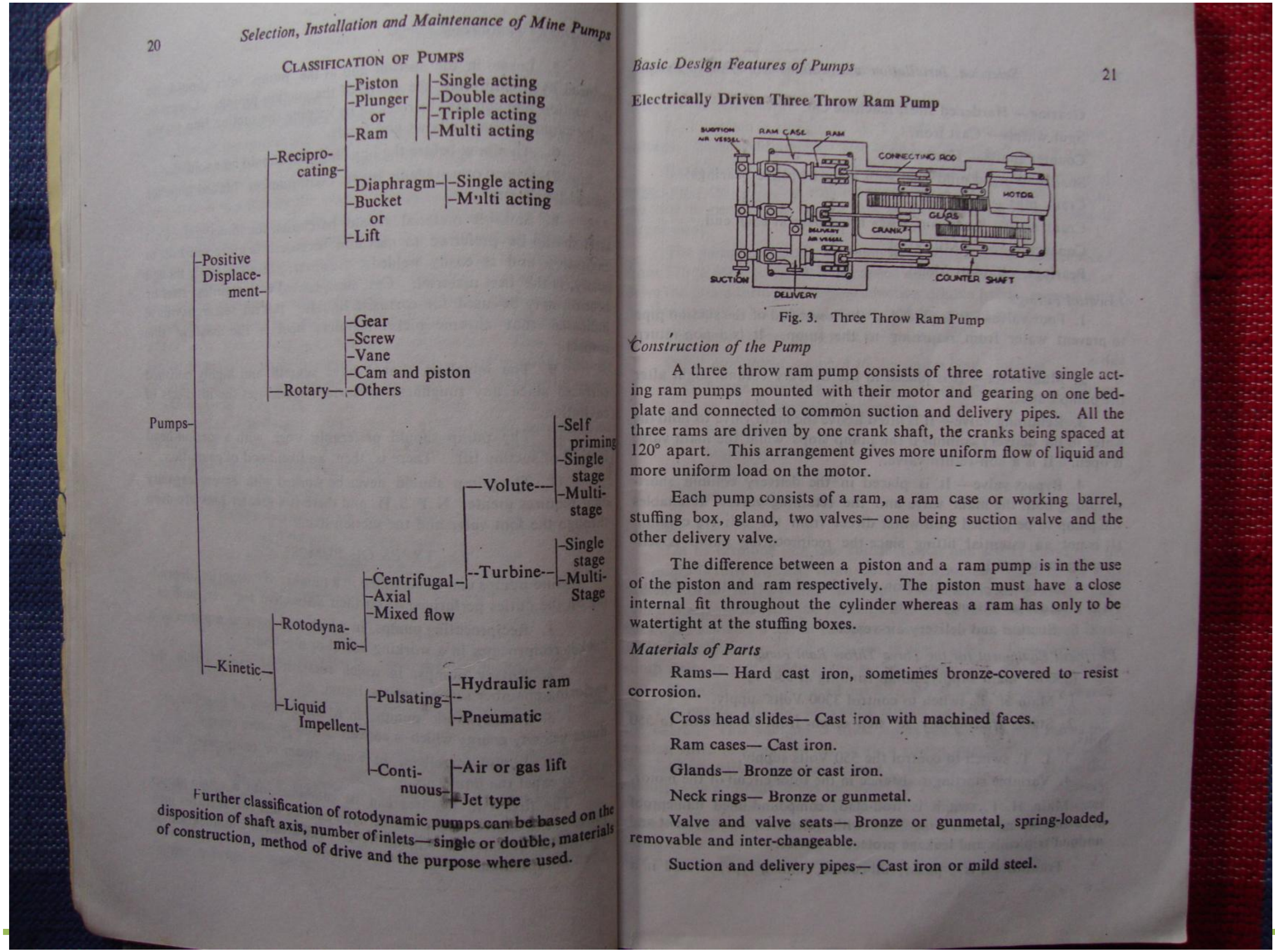
1. Reciprocating pumps, in which a plunger or a piston or a bucket reciprocates in a working barrel or a cylinder.

2. Rotary pumps, in which rotation of cams within the enclosing chamber scoops out the liquid.

3. Rotodynamic pumps, in which rotation of impeller produces velocity energy which is converted into pressure energy.

4. Liquid impellent, in which steam or compressed air is used to expel the liquid up.

The first two features can be combined into a single group called the 'Positive Displacement' type and the last two features into one group called the 'Kinetic' type. The detailed classification is given in a tabulated form.



CLASSIFICATION OF PUMPS

- Pumps
  - Positive Displacement
    - Reciprocating
      - Piston
      - Plunger or
      - Ram
        - Single acting
        - Double acting
        - Triple acting
        - Multi acting
      - Diaphragm
        - Single acting
        - Multi acting
      - Bucket or
      - Lift
    - Rotary
      - Gear
      - Screw
      - Vane
      - Cam and piston
      - Others
  - Kinetic
    - Rotodynamic
      - Centrifugal
        - Volute
          - Self priming
          - Single stage
          - Multi-stage
        - Turbine
          - Single stage
          - Multi-Stage
      - Axial
      - Mixed flow
    - Liquid Impellent
      - Pulsating
        - Hydraulic ram
        - Pneumatic
      - Continuous
        - Air or gas lift
        - Jet type

Further classification of rotodynamic pumps can be based on the disposition of shaft axis, number of inlets—single or double, materials of construction, method of drive and the purpose where used.

Electrically Driven Three Throw Ram Pump

Fig. 3. Three Throw Ram Pump

Construction of the Pump

A three throw ram pump consists of three rotative single acting ram pumps mounted with their motor and gearing on one bedplate and connected to common suction and delivery pipes. All the three rams are driven by one crank shaft, the cranks being spaced at 120° apart. This arrangement gives more uniform flow of liquid and more uniform load on the motor.

Each pump consists of a ram, a ram case or working barrel, stuffing box, gland, two valves— one being suction valve and the other delivery valve.

The difference between a piston and a ram pump is in the use of the piston and ram respectively. The piston must have a close internal fit throughout the cylinder whereas a ram has only to be watertight at the stuffing boxes.

Materials of Parts

Rams— Hard cast iron, sometimes bronze-covered to resist corrosion.

Cross head slides— Cast iron with machined faces.

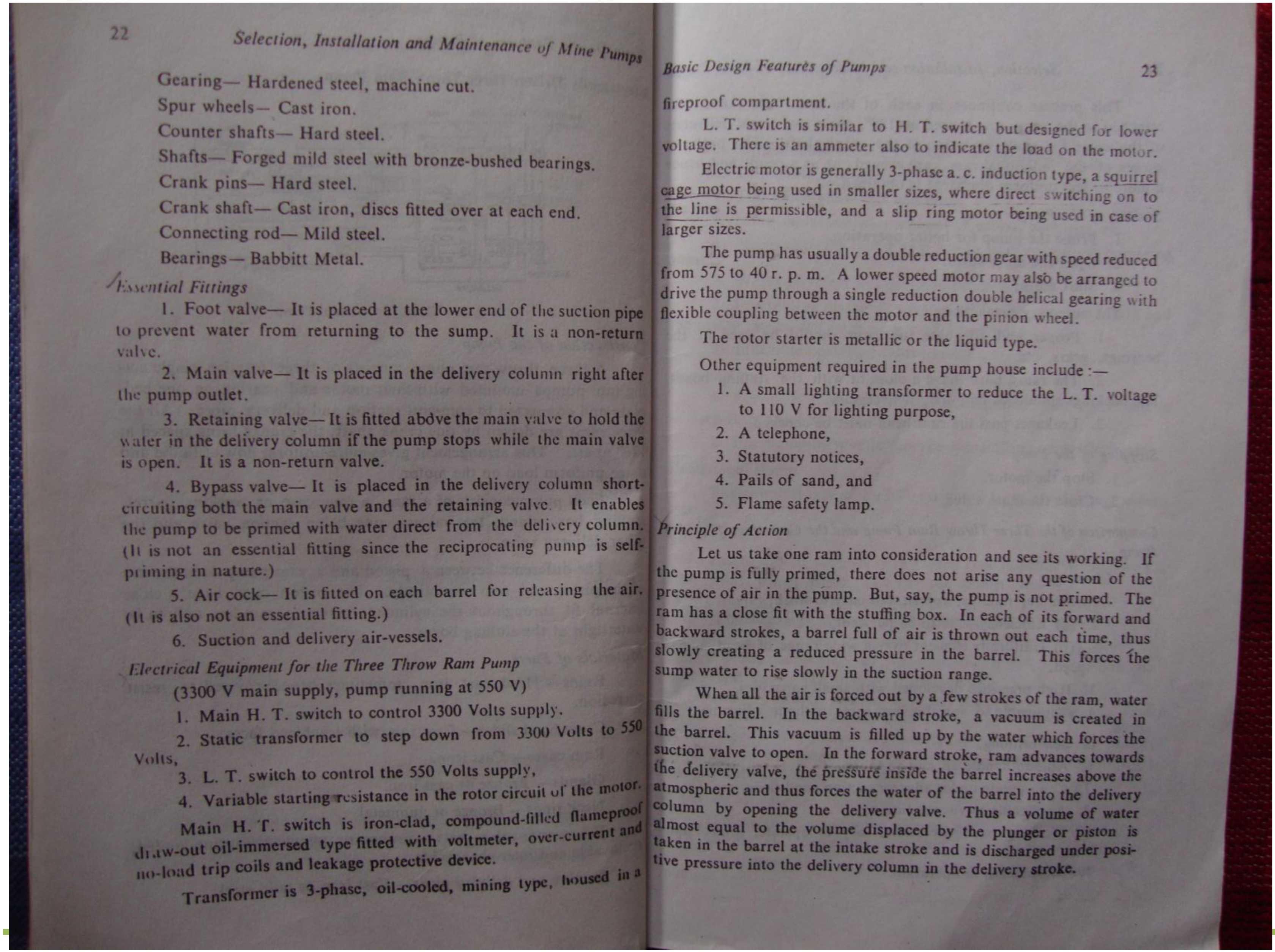
Ram cases— Cast iron.

Glands— Bronze or cast iron.

Neck rings— Bronze or gunmetal.

Valve and valve seats— Bronze or gunmetal, spring-loaded, removable and inter-changeable.

Suction and delivery pipes— Cast iron or mild steel.



Gearing— Hardened steel, machine cut.
Spur wheels— Cast iron.
Counter shafts— Hard steel.
Shafts— Forged mild steel with bronze-bushed bearings.
Crank pins— Hard steel.
Crank shaft— Cast iron, discs fitted over at each end.
Connecting rod— Mild steel.
Bearings— Babbitt Metal.

Essential Fittings

1. Foot valve— It is placed at the lower end of the suction pipe to prevent water from returning to the sump. It is a non-return valve.

2. Main valve— It is placed in the delivery column right after the pump outlet.

3. Retaining valve— It is fitted above the main valve to hold the water in the delivery column if the pump stops while the main valve is open. It is a non-return valve.

4. Bypass valve— It is placed in the delivery column short-circuiting both the main valve and the retaining valve. It enables the pump to be primed with water direct from the delivery column. (It is not an essential fitting since the reciprocating pump is self-priming in nature.)

5. Air cock— It is fitted on each barrel for releasing the air. (It is also not an essential fitting.)

6. Suction and delivery air-vessels.

Electrical Equipment for the Three Throw Ram Pump

(3300 V main supply, pump running at 550 V)

1. Main H. T. switch to control 3300 Volts supply.

2. Static transformer to step down from 3300 Volts to 550 Volts,

3. L. T. switch to control the 550 Volts supply,

4. Variable starting resistance in the rotor circuit of the motor.

Main H. T. switch is iron-clad, compound-filled flameproof draw-out oil-immersed type fitted with voltmeter, over-current and no-load trip coils and leakage protective device.

Transformer is 3-phase, oil-cooled, mining type, housed in a

fireproof compartment.

L. T. switch is similar to H. T. switch but designed for lower voltage. There is an ammeter also to indicate the load on the motor.

Electric motor is generally 3-phase a. c. induction type, a squirrel cage motor being used in smaller sizes, where direct switching on to the line is permissible, and a slip ring motor being used in case of larger sizes.

The pump has usually a double reduction gear with speed reduced from 575 to 40 r. p. m. A lower speed motor may also be arranged to drive the pump through a single reduction double helical gearing with flexible coupling between the motor and the pinion wheel.

The rotor starter is metallic or the liquid type.

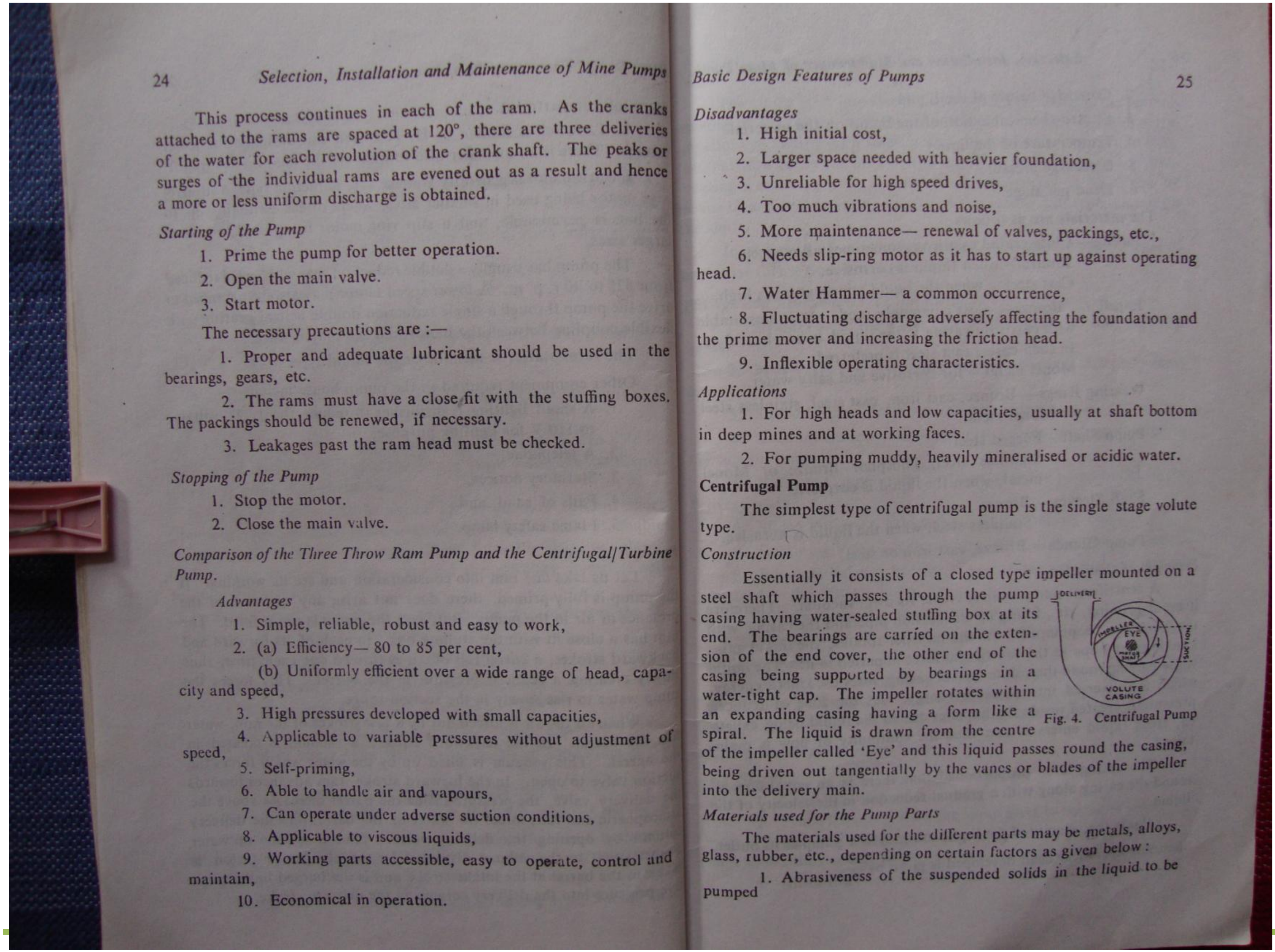
Other equipment required in the pump house include :—

1. A small lighting transformer to reduce the L. T. voltage to 110 V for lighting purpose,
2. A telephone,
3. Statutory notices,
4. Pails of sand, and
5. Flame safety lamp.

Principle of Action

Let us take one ram into consideration and see its working. If the pump is fully primed, there does not arise any question of the presence of air in the pump. But, say, the pump is not primed. The ram has a close fit with the stuffing box. In each of its forward and backward strokes, a barrel full of air is thrown out each time, thus slowly creating a reduced pressure in the barrel. This forces the sump water to rise slowly in the suction range.

When all the air is forced out by a few strokes of the ram, water fills the barrel. In the backward stroke, a vacuum is created in the barrel. This vacuum is filled up by the water which forces the suction valve to open. In the forward stroke, ram advances towards the delivery valve, the pressure inside the barrel increases above the atmospheric and thus forces the water of the barrel into the delivery column by opening the delivery valve. Thus a volume of water almost equal to the volume displaced by the plunger or piston is taken in the barrel at the intake stroke and is discharged under positive pressure into the delivery column in the delivery stroke.



This process continues in each of the ram. As the cranks attached to the rams are spaced at 120°, there are three deliveries of the water for each revolution of the crank shaft. The peaks or surges of the individual rams are evened out as a result and hence a more or less uniform discharge is obtained.

Starting of the Pump

1. Prime the pump for better operation.
2. Open the main valve.
3. Start motor.

The necessary precautions are :—

1. Proper and adequate lubricant should be used in the bearings, gears, etc.
2. The rams must have a close fit with the stuffing boxes. The packings should be renewed, if necessary.
3. Leakages past the ram head must be checked.

Stopping of the Pump

1. Stop the motor.
2. Close the main valve.

Comparison of the Three Throw Ram Pump and the Centrifugal/Turbine Pump.

Advantages

1. Simple, reliable, robust and easy to work,
2. (a) Efficiency— 80 to 85 per cent,
   (b) Uniformly efficient over a wide range of head, capacity and speed,
3. High pressures developed with small capacities,
4. Applicable to variable pressures without adjustment of speed,
5. Self-priming,
6. Able to handle air and vapours,
7. Can operate under adverse suction conditions,
8. Applicable to viscous liquids,
9. Working parts accessible, easy to operate, control and maintain,
10. Economical in operation.

Disadvantages

1. High initial cost,
2. Larger space needed with heavier foundation,
3. Unreliable for high speed drives,
4. Too much vibrations and noise,
5. More maintenance— renewal of valves, packings, etc.,
6. Needs slip-ring motor as it has to start up against operating head.
7. Water Hammer— a common occurrence,
8. Fluctuating discharge adversely affecting the foundation and the prime mover and increasing the friction head.
9. Inflexible operating characteristics.

Applications

1. For high heads and low capacities, usually at shaft bottom in deep mines and at working faces.
2. For pumping muddy, heavily mineralised or acidic water.

Centrifugal Pump

The simplest type of centrifugal pump is the single stage volute type.

Construction

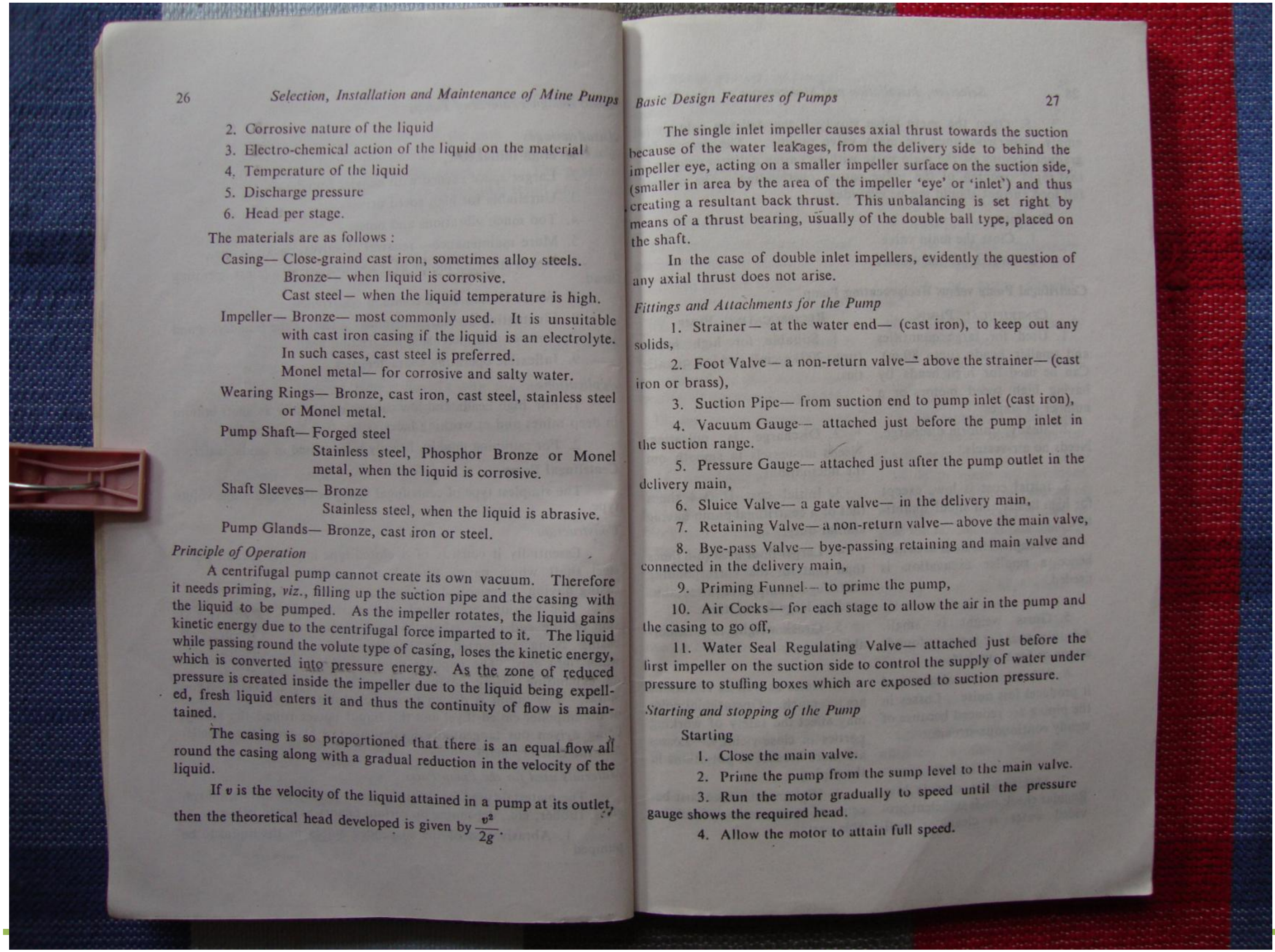
Essentially it consists of a closed type impeller mounted on a steel shaft which passes through the pump casing having water-sealed stuffing box at its end. The bearings are carried on the extension of the end cover, the other end of the casing being supported by bearings in a water-tight cap. The impeller rotates within an expanding casing having a form like a spiral. The liquid is drawn from the centre of the impeller called 'Eye' and this liquid passes round the casing, being driven out tangentially by the vanes or blades of the impeller into the delivery main.

Fig. 4. Centrifugal Pump

Materials used for the Pump Parts

The materials used for the different parts may be metals, alloys, glass, rubber, etc., depending on certain factors as given below :

1. Abrasiveness of the suspended solids in the liquid to be pumped



2. Corrosive nature of the liquid
3. Electro-chemical action of the liquid on the material
4. Temperature of the liquid
5. Discharge pressure
6. Head per stage.

The materials are as follows :

Casing— Close-graind cast iron, sometimes alloy steels.
Bronze— when liquid is corrosive.
Cast steel— when the liquid temperature is high.

Impeller— Bronze— most commonly used. It is unsuitable with cast iron casing if the liquid is an electrolyte. In such cases, cast steel is preferred.
Monel metal— for corrosive and salty water.

Wearing Rings— Bronze, cast iron, cast steel, stainless steel or Monel metal.

Pump Shaft— Forged steel
Stainless steel, Phosphor Bronze or Monel metal, when the liquid is corrosive.

Shaft Sleeves— Bronze
Stainless steel, when the liquid is abrasive.

Pump Glands— Bronze, cast iron or steel.

Principle of Operation

A centrifugal pump cannot create its own vacuum. Therefore it needs priming, *viz.*, filling up the suction pipe and the casing with the liquid to be pumped. As the impeller rotates, the liquid gains kinetic energy due to the centrifugal force imparted to it. The liquid while passing round the volute type of casing, loses the kinetic energy, which is converted into pressure energy. As the zone of reduced pressure is created inside the impeller due to the liquid being expelled, fresh liquid enters it and thus the continuity of flow is maintained.

The casing is so proportioned that there is an equal flow all round the casing along with a gradual reduction in the velocity of the liquid.

If v is the velocity of the liquid attained in a pump at its outlet, then the theoretical head developed is given by $\frac{v^2}{2g}$.

The single inlet impeller causes axial thrust towards the suction because of the water leakages, from the delivery side to behind the impeller eye, acting on a smaller impeller surface on the suction side, (smaller in area by the area of the impeller 'eye' or 'inlet') and thus creating a resultant back thrust. This unbalancing is set right by means of a thrust bearing, usually of the double ball type, placed on the shaft.

In the case of double inlet impellers, evidently the question of any axial thrust does not arise.

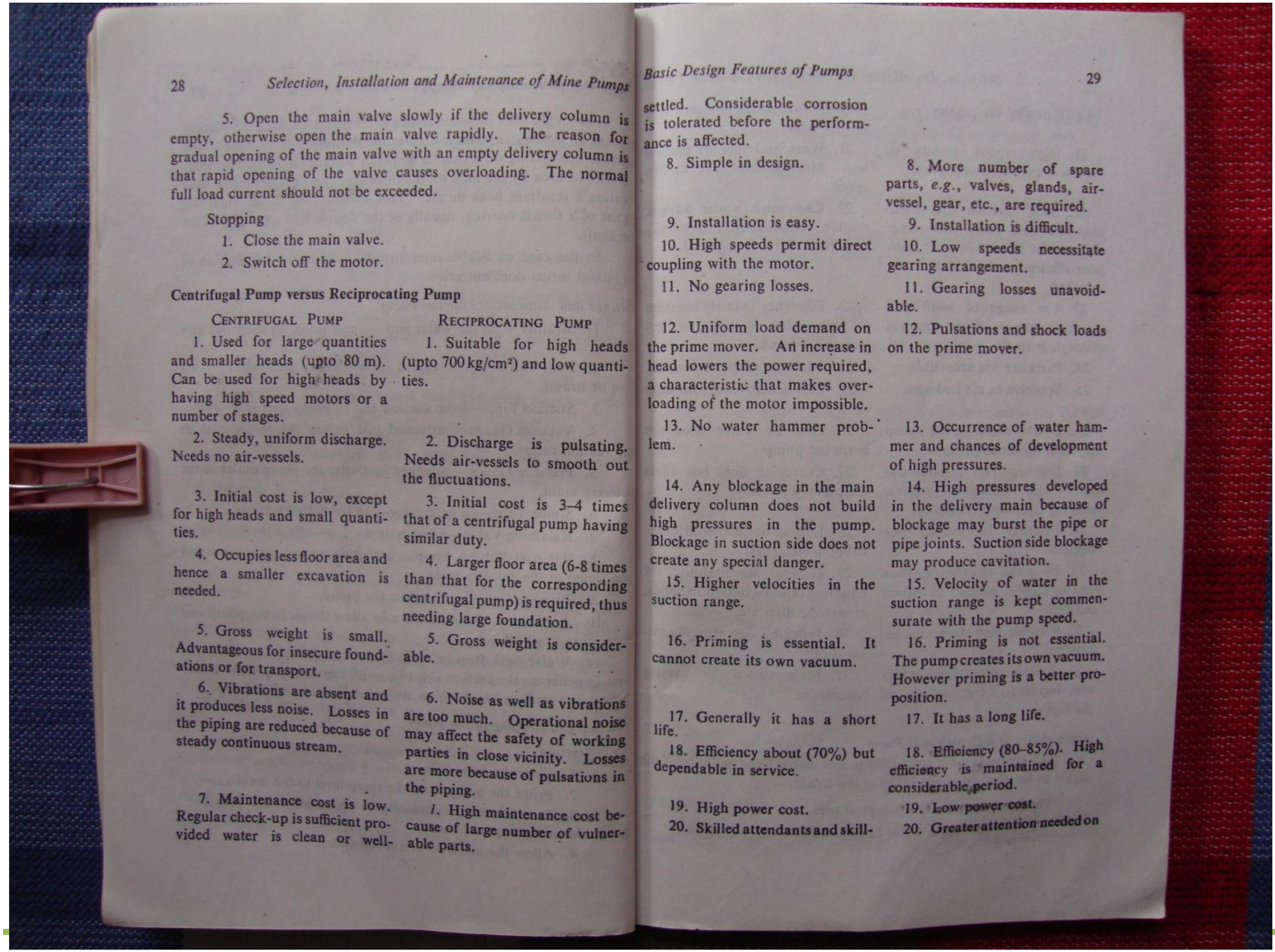
Fittings and Attachments for the Pump

1. Strainer— at the water end— (cast iron), to keep out any solids,
2. Foot Valve— a non-return valve— above the strainer— (cast iron or brass),
3. Suction Pipe— from suction end to pump inlet (cast iron),
4. Vacuum Gauge— attached just before the pump inlet in the suction range.
5. Pressure Gauge— attached just after the pump outlet in the delivery main,
6. Sluice Valve— a gate valve— in the delivery main,
7. Retaining Valve— a non-return valve— above the main valve,
8. Bye-pass Valve— bye-passing retaining and main valve and connected in the delivery main,
9. Priming Funnel— to prime the pump,
10. Air Cocks— for each stage to allow the air in the pump and the casing to go off,
11. Water Seal Regulating Valve— attached just before the first impeller on the suction side to control the supply of water under pressure to stuffing boxes which are exposed to suction pressure.

Starting and stopping of the Pump

Starting

1. Close the main valve.
2. Prime the pump from the sump level to the main valve.
3. Run the motor gradually to speed until the pressure gauge shows the required head.
4. Allow the motor to attain full speed.



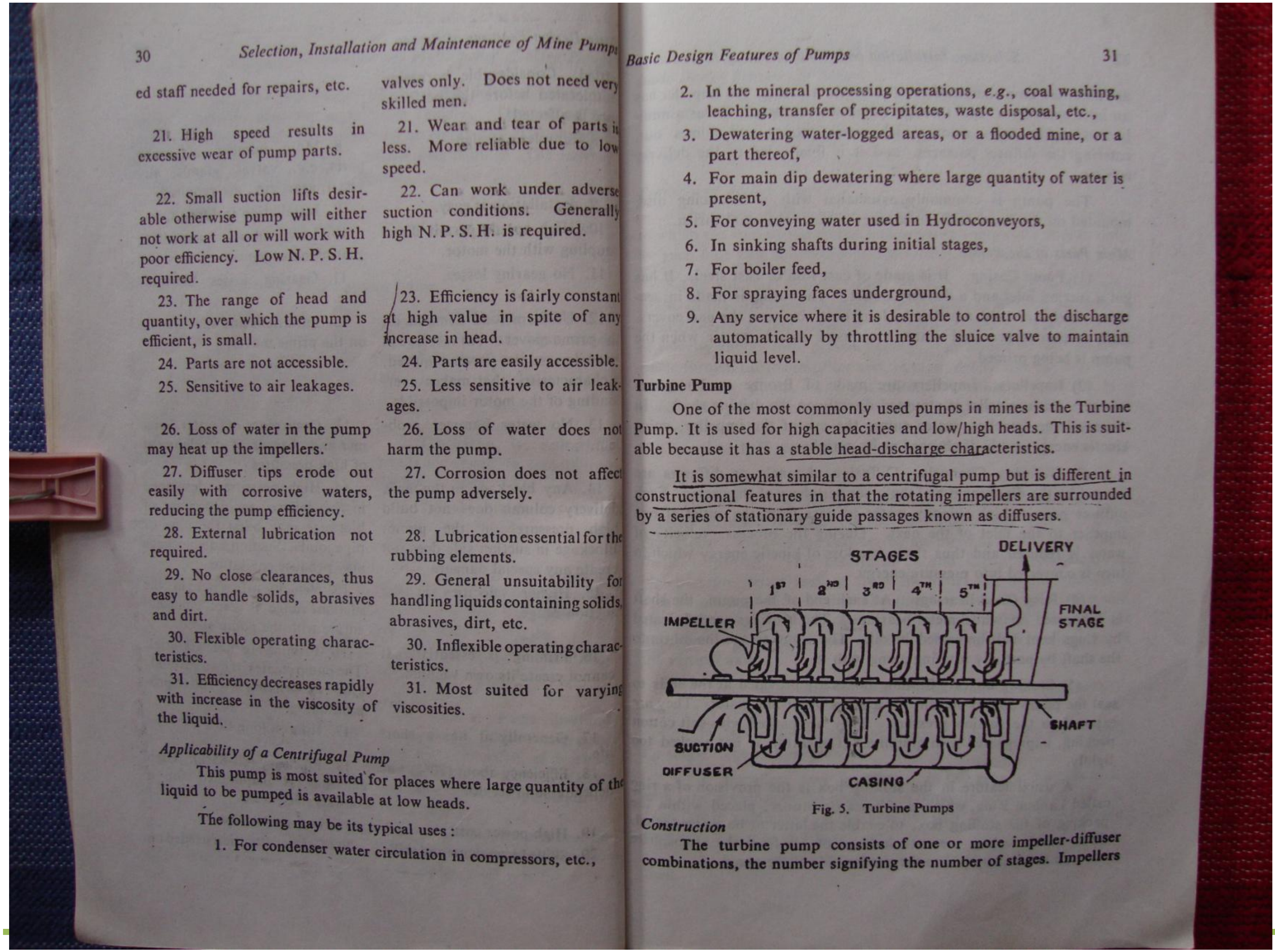
5. Open the main valve slowly if the delivery column is empty, otherwise open the main valve rapidly. The reason for gradual opening of the main valve with an empty delivery column is that rapid opening of the valve causes overloading. The normal full load current should not be exceeded.

Stopping

1. Close the main valve.
2. Switch off the motor.

Centrifugal Pump versus Reciprocating Pump

CENTRIFUGAL PUMP	RECIPROCATING PUMP
1. Used for large quantities and smaller heads (upto 80 m). Can be used for high heads by having high speed motors or a number of stages.	1. Suitable for high heads (upto 700 kg/cm²) and low quantities.
2. Steady, uniform discharge. Needs no air-vessels.	2. Discharge is pulsating. Needs air-vessels to smooth out the fluctuations.
3. Initial cost is low, except for high heads and small quantities.	3. Initial cost is 3–4 times that of a centrifugal pump having similar duty.
4. Occupies less floor area and hence a smaller excavation is needed.	4. Larger floor area (6-8 times than that for the corresponding centrifugal pump) is required, thus needing large foundation.
5. Gross weight is small. Advantageous for insecure foundations or for transport.	5. Gross weight is considerable.
6. Vibrations are absent and it produces less noise. Losses in the piping are reduced because of steady continuous stream.	6. Noise as well as vibrations are too much. Operational noise may affect the safety of working parties in close vicinity. Losses are more because of pulsations in the piping.
7. Maintenance cost is low. Regular check-up is sufficient provided water is clean or well-settled. Considerable corrosion is tolerated before the performance is affected.	7. High maintenance cost because of large number of vulnerable parts.
8. Simple in design.	8. More number of spare parts, *e.g.*, valves, glands, air-vessel, gear, etc., are required.
9. Installation is easy.	9. Installation is difficult.
10. High speeds permit direct coupling with the motor.	10. Low speeds necessitate gearing arrangement.
11. No gearing losses.	11. Gearing losses unavoidable.
12. Uniform load demand on the prime mover. An increase in head lowers the power required, a characteristic that makes overloading of the motor impossible.	12. Pulsations and shock loads on the prime mover.
13. No water hammer problem.	13. Occurrence of water hammer and chances of development of high pressures.
14. Any blockage in the main delivery column does not build high pressures in the pump. Blockage in suction side does not create any special danger.	14. High pressures developed in the delivery main because of blockage may burst the pipe or pipe joints. Suction side blockage may produce cavitation.
15. Higher velocities in the suction range.	15. Velocity of water in the suction range is kept commensurate with the pump speed.
16. Priming is essential. It cannot create its own vacuum.	16. Priming is not essential. The pump creates its own vacuum. However priming is a better proposition.
17. Generally it has a short life.	17. It has a long life.
18. Efficiency about (70%) but dependable in service.	18. Efficiency (80–85%). High efficiency is maintained for a considerable period.
19. High power cost.	19. Low power cost.
20. Skilled attendants and skill-	20. Greater attention needed on



ed staff needed for repairs, etc.	valves only. Does not need ver skilled men.
21. High speed results in excessive wear of pump parts.	21. Wear and tear of parts i less. More reliable due to low speed.
22. Small suction lifts desirable otherwise pump will either not work at all or will work with poor efficiency. Low N. P. S. H. required.	22. Can work under adverse suction conditions. Generally high N. P. S. H. is required.
23. The range of head and quantity, over which the pump is efficient, is small.	23. Efficiency is fairly constant at high value in spite of any increase in head.
24. Parts are not accessible.	24. Parts are easily accessible.
25. Sensitive to air leakages.	25. Less sensitive to air leakages.
26. Loss of water in the pump may heat up the impellers.	26. Loss of water does not harm the pump.
27. Diffuser tips erode out easily with corrosive waters, reducing the pump efficiency.	27. Corrosion does not affect the pump adversely.
28. External lubrication not required.	28. Lubrication essential for the rubbing elements.
29. No close clearances, thus easy to handle solids, abrasives and dirt.	29. General unsuitability for handling liquids containing solids, abrasives, dirt, etc.
30. Flexible operating characteristics.	30. Inflexible operating characteristics.
31. Efficiency decreases rapidly with increase in the viscosity of the liquid.	31. Most suited for varyin viscosities.

Applicability of a Centrifugal Pump

This pump is most suited for places where large quantity of the liquid to be pumped is available at low heads.

The following may be its typical uses :

1. For condenser water circulation in compressors, etc.,

2. In the mineral processing operations, *e.g.*, coal washing, leaching, transfer of precipitates, waste disposal, etc.,
3. Dewatering water-logged areas, or a flooded mine, or a part thereof,
4. For main dip dewatering where large quantity of water is present,
5. For conveying water used in Hydroconveyors,
6. In sinking shafts during initial stages,
7. For boiler feed,
8. For spraying faces underground,
9. Any service where it is desirable to control the discharge automatically by throttling the sluice valve to maintain liquid level.

Turbine Pump

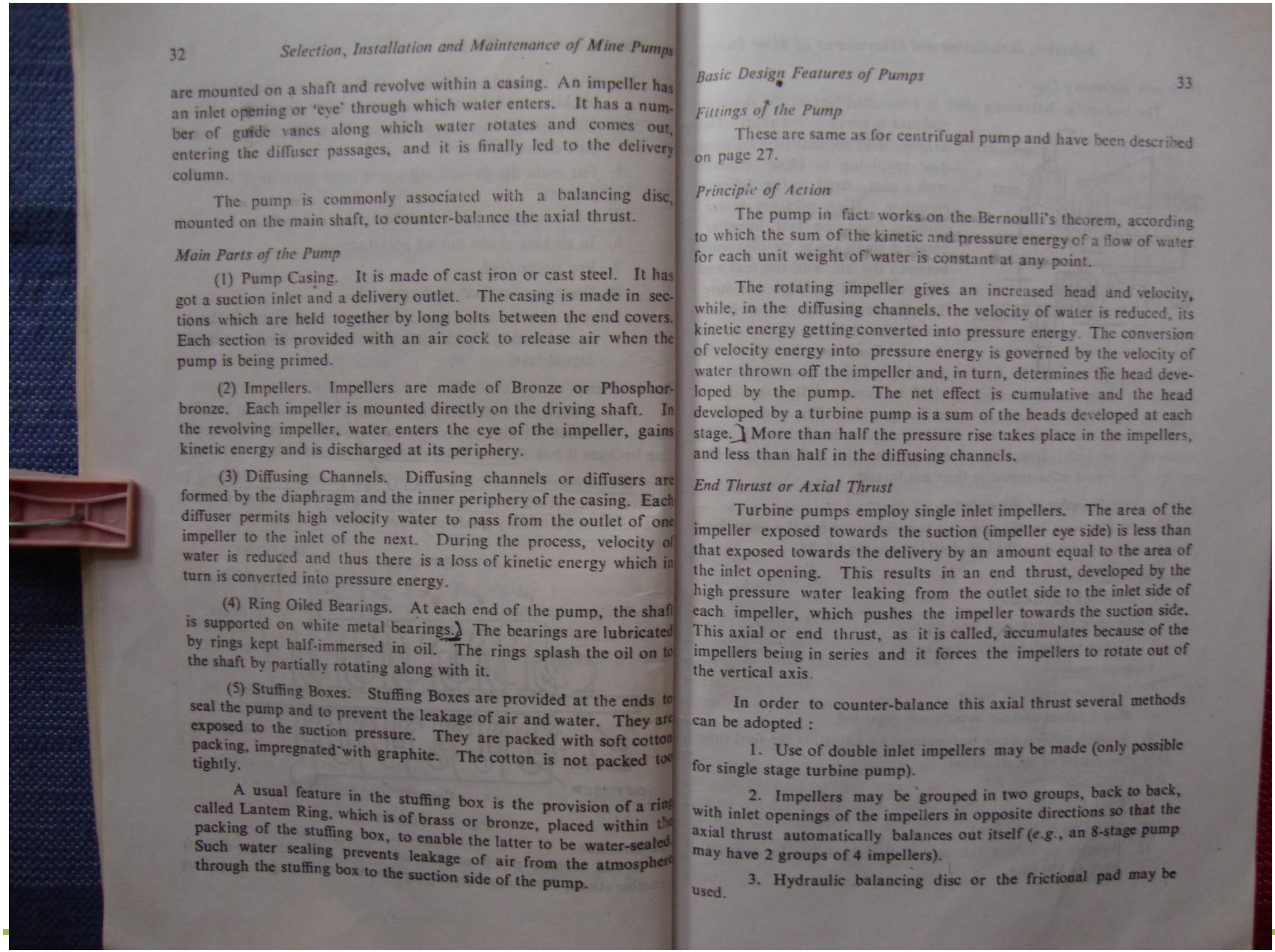
One of the most commonly used pumps in mines is the Turbine Pump. It is used for high capacities and low/high heads. This is suitable because it has a stable head-discharge characteristics.

It is somewhat similar to a centrifugal pump but is different in constructional features in that the rotating impellers are surrounded by a series of stationary guide passages known as diffusers.

Fig. 5. Turbine Pumps

Construction

The turbine pump consists of one or more impeller-diffuser combinations, the number signifying the number of stages. Impellers



are mounted on a shaft and revolve within a casing. An impeller has an inlet opening or 'eye' through which water enters. It has a number of guide vanes along which water rotates and comes out, entering the diffuser passages, and it is finally led to the delivery column.

The pump is commonly associated with a balancing disc, mounted on the main shaft, to counter-balance the axial thrust.

Main Parts of the Pump

(1) Pump Casing. It is made of cast iron or cast steel. It has got a suction inlet and a delivery outlet. The casing is made in sections which are held together by long bolts between the end covers. Each section is provided with an air cock to release air when the pump is being primed.

(2) Impellers. Impellers are made of Bronze or Phosphor-bronze. Each impeller is mounted directly on the driving shaft. In the revolving impeller, water enters the eye of the impeller, gains kinetic energy and is discharged at its periphery.

(3) Diffusing Channels. Diffusing channels or diffusers are formed by the diaphragm and the inner periphery of the casing. Each diffuser permits high velocity water to pass from the outlet of one impeller to the inlet of the next. During the process, velocity of water is reduced and thus there is a loss of kinetic energy which in turn is converted into pressure energy.

(4) Ring Oiled Bearings. At each end of the pump, the shaft is supported on white metal bearings. The bearings are lubricated by rings kept half-immersed in oil. The rings splash the oil on to the shaft by partially rotating along with it.

(5) Stuffing Boxes. Stuffing Boxes are provided at the ends to seal the pump and to prevent the leakage of air and water. They are exposed to the suction pressure. They are packed with soft cotton packing, impregnated with graphite. The cotton is not packed too tightly.

A usual feature in the stuffing box is the provision of a ring called Lantern Ring, which is of brass or bronze, placed within the packing of the stuffing box, to enable the latter to be water-sealed. Such water sealing prevents leakage of air from the atmosphere through the stuffing box to the suction side of the pump.

Fittings of the Pump

These are same as for centrifugal pump and have been described on page 27.

Principle of Action

The pump in fact works on the Bernoulli's theorem, according to which the sum of the kinetic and pressure energy of a flow of water for each unit weight of water is constant at any point.

The rotating impeller gives an increased head and velocity, while, in the diffusing channels, the velocity of water is reduced, its kinetic energy getting converted into pressure energy. The conversion of velocity energy into pressure energy is governed by the velocity of water thrown off the impeller and, in turn, determines the head developed by the pump. The net effect is cumulative and the head developed by a turbine pump is a sum of the heads developed at each stage. More than half the pressure rise takes place in the impellers, and less than half in the diffusing channels.

End Thrust or Axial Thrust

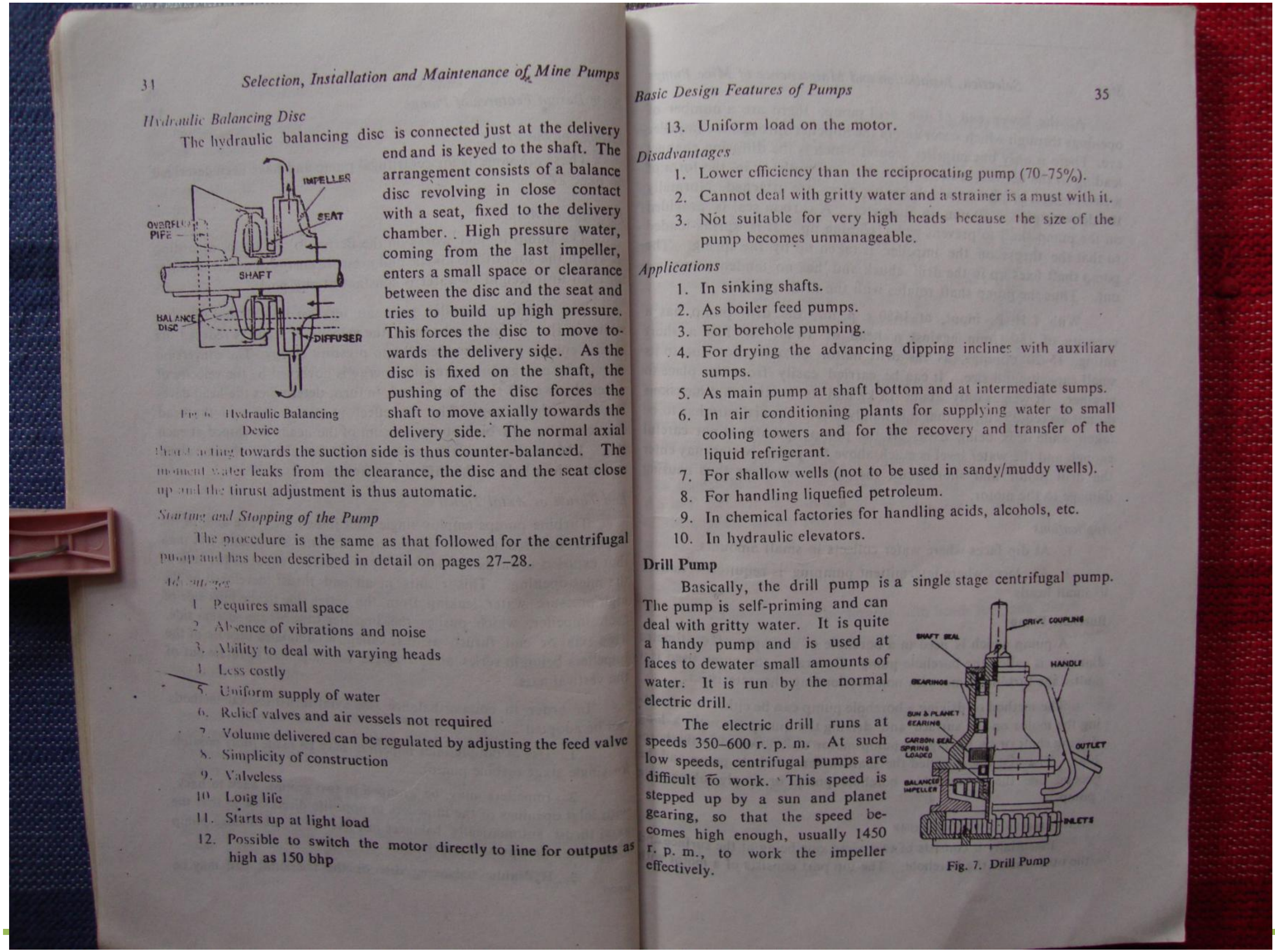
Turbine pumps employ single inlet impellers. The area of the impeller exposed towards the suction (impeller eye side) is less than that exposed towards the delivery by an amount equal to the area of the inlet opening. This results in an end thrust, developed by the high pressure water leaking from the outlet side to the inlet side of each impeller, which pushes the impeller towards the suction side. This axial or end thrust, as it is called, accumulates because of the impellers being in series and it forces the impellers to rotate out of the vertical axis.

In order to counter-balance this axial thrust several methods can be adopted :

1. Use of double inlet impellers may be made (only possible for single stage turbine pump).

2. Impellers may be grouped in two groups, back to back, with inlet openings of the impellers in opposite directions so that the axial thrust automatically balances out itself (*e.g.*, an 8-stage pump may have 2 groups of 4 impellers).

3. Hydraulic balancing disc or the frictional pad may be used.



Hydraulic Balancing Disc

The hydraulic balancing disc is connected just at the delivery end and is keyed to the shaft. The arrangement consists of a balance disc revolving in close contact with a seat, fixed to the delivery chamber. High pressure water, coming from the last impeller, enters a small space or clearance between the disc and the seat and tries to build up high pressure. This forces the disc to move towards the delivery side. As the disc is fixed on the shaft, the pushing of the disc forces the shaft to move axially towards the delivery side. The normal axial thrust acting towards the suction side is thus counter-balanced. The moment water leaks from the clearance, the disc and the seat close up and the thrust adjustment is thus automatic.

Fig. 6. Hydraulic Balancing Device

Starting and Stopping of the Pump

The procedure is the same as that followed for the centrifugal pump and has been described in detail on pages 27–28.

Advantages

1. Requires small space
2. Absence of vibrations and noise
3. Ability to deal with varying heads
4. Less costly
5. Uniform supply of water
6. Relief valves and air vessels not required
7. Volume delivered can be regulated by adjusting the feed valve
8. Simplicity of construction
9. Valveless
10. Long life
11. Starts up at light load
12. Possible to switch the motor directly to line for outputs as high as 150 bhp

13. Uniform load on the motor.

Disadvantages

1. Lower efficiency than the reciprocating pump (70–75%).
2. Cannot deal with gritty water and a strainer is a must with it.
3. Not suitable for very high heads because the size of the pump becomes unmanageable.

Applications

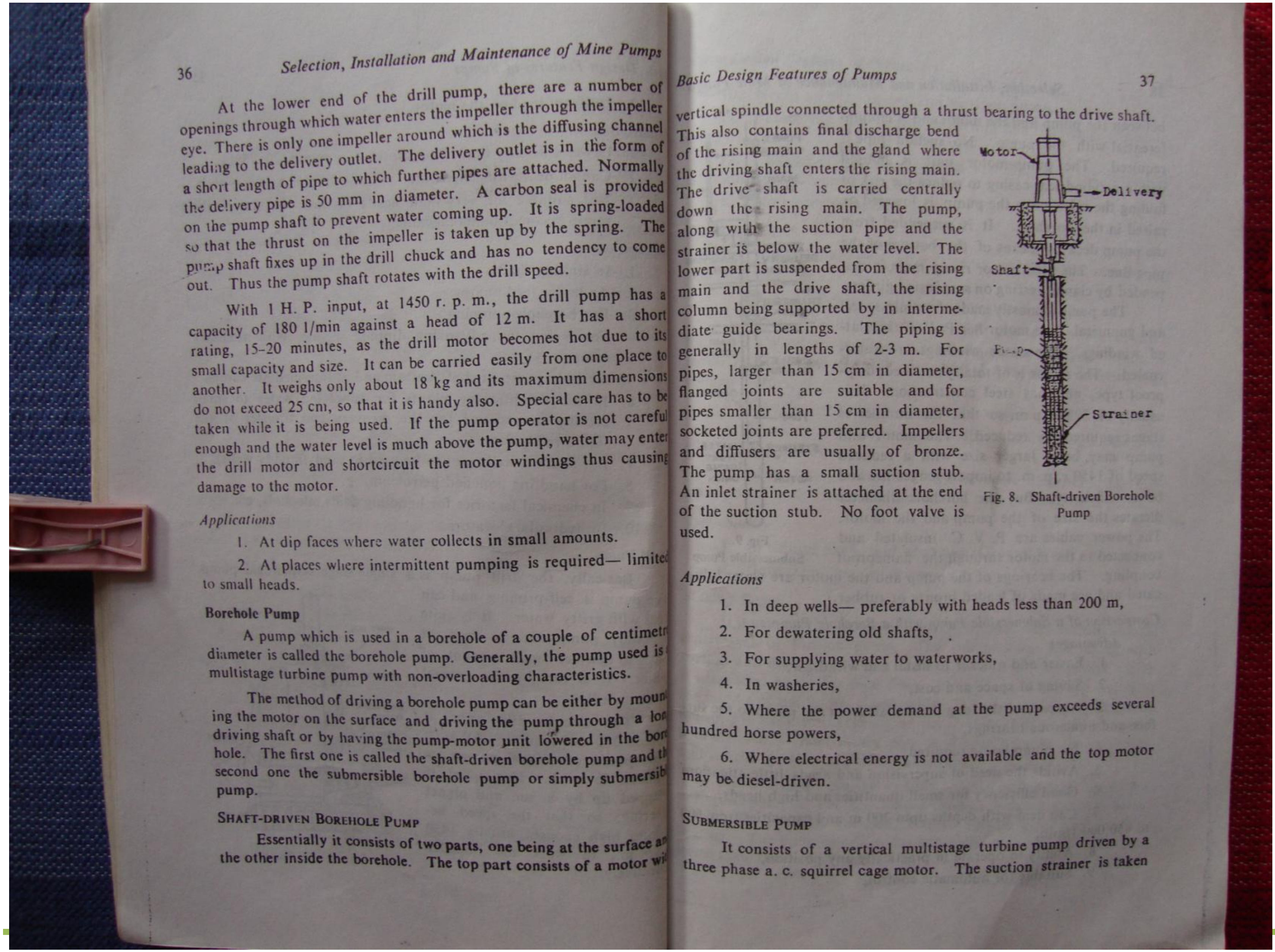
1. In sinking shafts.
2. As boiler feed pumps.
3. For borehole pumping.
4. For drying the advancing dipping inclines with auxiliary sumps.
5. As main pump at shaft bottom and at intermediate sumps.
6. In air conditioning plants for supplying water to small cooling towers and for the recovery and transfer of the liquid refrigerant.
7. For shallow wells (not to be used in sandy/muddy wells).
8. For handling liquefied petroleum.
9. In chemical factories for handling acids, alcohols, etc.
10. In hydraulic elevators.

Drill Pump

Basically, the drill pump is a single stage centrifugal pump. The pump is self-priming and can deal with gritty water. It is quite a handy pump and is used at faces to dewater small amounts of water. It is run by the normal electric drill.

The electric drill runs at speeds 350–600 r. p. m. At such low speeds, centrifugal pumps are difficult to work. This speed is stepped up by a sun and planet gearing, so that the speed becomes high enough, usually 1450 r. p. m., to work the impeller effectively.

Fig. 7. Drill Pump



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At the lower end of the drill pump, there are a number of openings through which water enters the impeller through the impeller eye. There is only one impeller around which is the diffusing channel leading to the delivery outlet. The delivery outlet is in the form of a short length of pipe to which further pipes are attached. Normally the delivery pipe is 50 mm in diameter. A carbon seal is provided on the pump shaft to prevent water coming up. It is spring-loaded so that the thrust on the impeller is taken up by the spring. The pump shaft fixes up in the drill chuck and has no tendency to come out. Thus the pump shaft rotates with the drill speed.

With 1 H. P. input, at 1450 r. p. m., the drill pump has a capacity of 180 l/min against a head of 12 m. It has a short rating, 15–20 minutes, as the drill motor becomes hot due to its small capacity and size. It can be carried easily from one place to another. It weighs only about 18 kg and its maximum dimensions do not exceed 25 cm, so that it is handy also. Special care has to be taken while it is being used. If the pump operator is not careful enough and the water level is much above the pump, water may enter the drill motor and shortcircuit the motor windings thus causing damage to the motor.

Applications

1. At dip faces where water collects in small amounts.
2. At places where intermittent pumping is required— limited to small heads.

Borehole Pump

A pump which is used in a borehole of a couple of centimetr diameter is called the borehole pump. Generally, the pump used is multistage turbine pump with non-overloading characteristics.

The method of driving a borehole pump can be either by moun ing the motor on the surface and driving the pump through a lon driving shaft or by having the pump-motor unit lowered in the bor hole. The first one is called the shaft-driven borehole pump and th second one the submersible borehole pump or simply submersib pump.

SHAFT-DRIVEN BOREHOLE PUMP

Essentially it consists of two parts, one being at the surface an the other inside the borehole. The top part consists of a motor wi

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vertical spindle connected through a thrust bearing to the drive shaft. This also contains final discharge bend of the rising main and the gland where the driving shaft enters the rising main. The drive shaft is carried centrally down the rising main. The pump, along with the suction pipe and the strainer is below the water level. The lower part is suspended from the rising main and the drive shaft, the rising column being supported by in intermediate guide bearings. The piping is generally in lengths of 2-3 m. For pipes, larger than 15 cm in diameter, flanged joints are suitable and for pipes smaller than 15 cm in diameter, socketed joints are preferred. Impellers and diffusers are usually of bronze. The pump has a small suction stub. An inlet strainer is attached at the end of the suction stub. No foot valve is used.

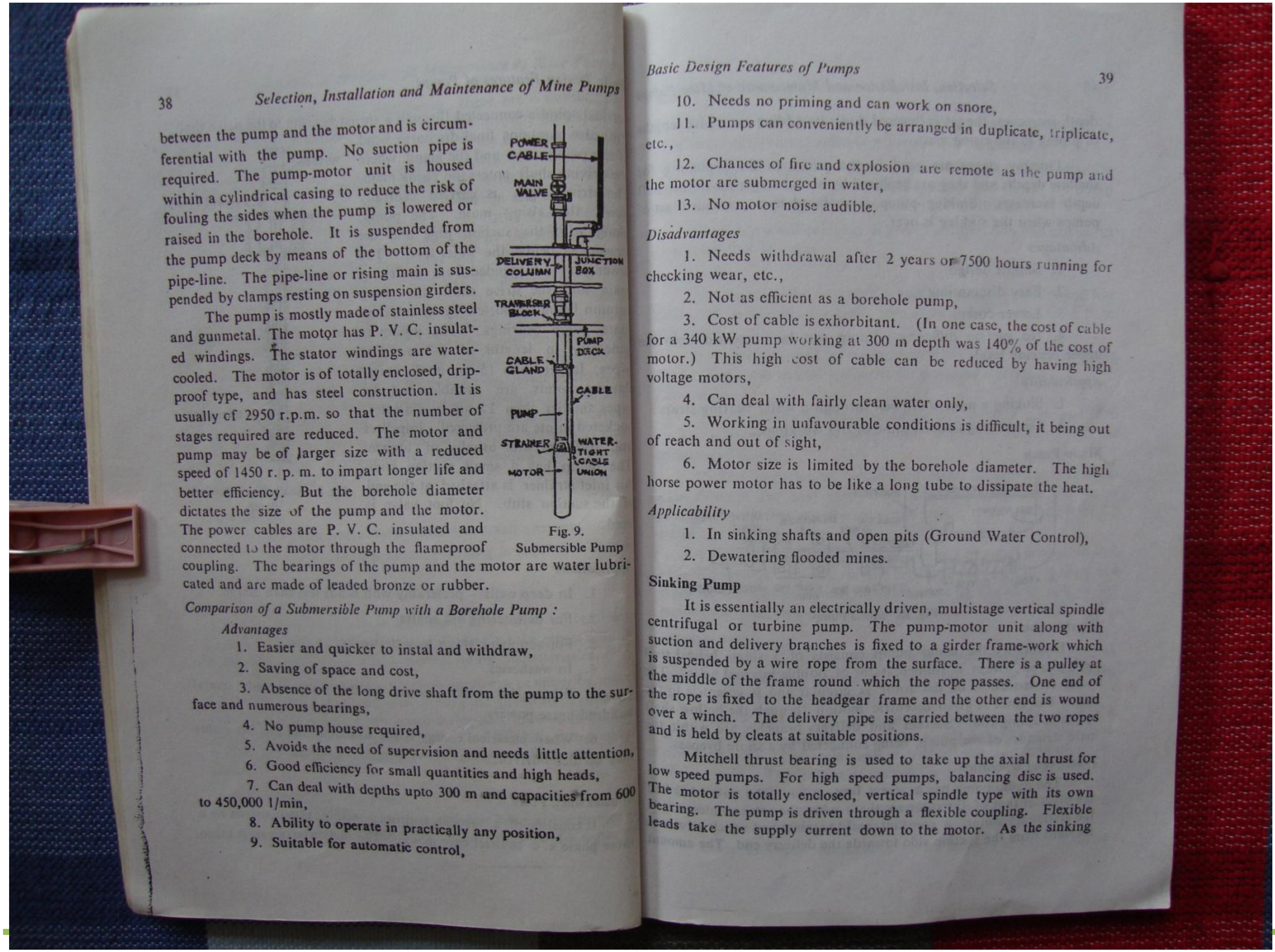
Fig. 8. Shaft-driven Borehole Pump

Applications

1. In deep wells— preferably with heads less than 200 m,
2. For dewatering old shafts,
3. For supplying water to waterworks,
4. In washeries,
5. Where the power demand at the pump exceeds several hundred horse powers,
6. Where electrical energy is not available and the top motor may be diesel-driven.

SUBMERSIBLE PUMP

It consists of a vertical multistage turbine pump driven by a three phase a. c. squirrel cage motor. The suction strainer is taken



POWER CABLE
MAIN VALVE
DELIVERY COLUMN
JUNCTION BOX
TRAVERSER BLOCK
PUMP DECK
CABLE GLAND
CABLE
PUMP
STRAINER
WATER-TIGHT CABLE UNION
MOTOR

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between the pump and the motor and is circumferential with the pump. No suction pipe is required. The pump-motor unit is housed within a cylindrical casing to reduce the risk of fouling the sides when the pump is lowered or raised in the borehole. It is suspended from the pump deck by means of the bottom of the pipe-line. The pipe-line or rising main is suspended by clamps resting on suspension girders.

The pump is mostly made of stainless steel and gunmetal. The motor has P. V. C. insulated windings. The stator windings are water-cooled. The motor is of totally enclosed, drip-proof type, and has steel construction. It is usually of 2950 r.p.m. so that the number of stages required are reduced. The motor and pump may be of larger size with a reduced speed of 1450 r. p. m. to impart longer life and better efficiency. But the borehole diameter dictates the size of the pump and the motor. The power cables are P. V. C. insulated and connected to the motor through the flameproof coupling. The bearings of the pump and the motor are water lubricated and are made of leaded bronze or rubber.

Fig. 9.
Submersible Pump

Comparison of a Submersible Pump with a Borehole Pump :

Advantages

1. Easier and quicker to instal and withdraw,
2. Saving of space and cost,
3. Absence of the long drive shaft from the pump to the surface and numerous bearings,
4. No pump house required,
5. Avoids the need of supervision and needs little attention,
6. Good efficiency for small quantities and high heads,
7. Can deal with depths upto 300 m and capacities from 600 to 450,000 l/min,
8. Ability to operate in practically any position,
9. Suitable for automatic control,

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10. Needs no priming and can work on snore,
11. Pumps can conveniently be arranged in duplicate, triplicate, etc.,
12. Chances of fire and explosion are remote as the pump and the motor are submerged in water,
13. No motor noise audible.

Disadvantages

1. Needs withdrawal after 2 years or 7500 hours running for checking wear, etc.,
2. Not as efficient as a borehole pump,
3. Cost of cable is exhorbitant. (In one case, the cost of cable for a 340 kW pump working at 300 m depth was 140% of the cost of motor.) This high cost of cable can be reduced by having high voltage motors,
4. Can deal with fairly clean water only,
5. Working in unfavourable conditions is difficult, it being out of reach and out of sight,
6. Motor size is limited by the borehole diameter. The high horse power motor has to be like a long tube to dissipate the heat.

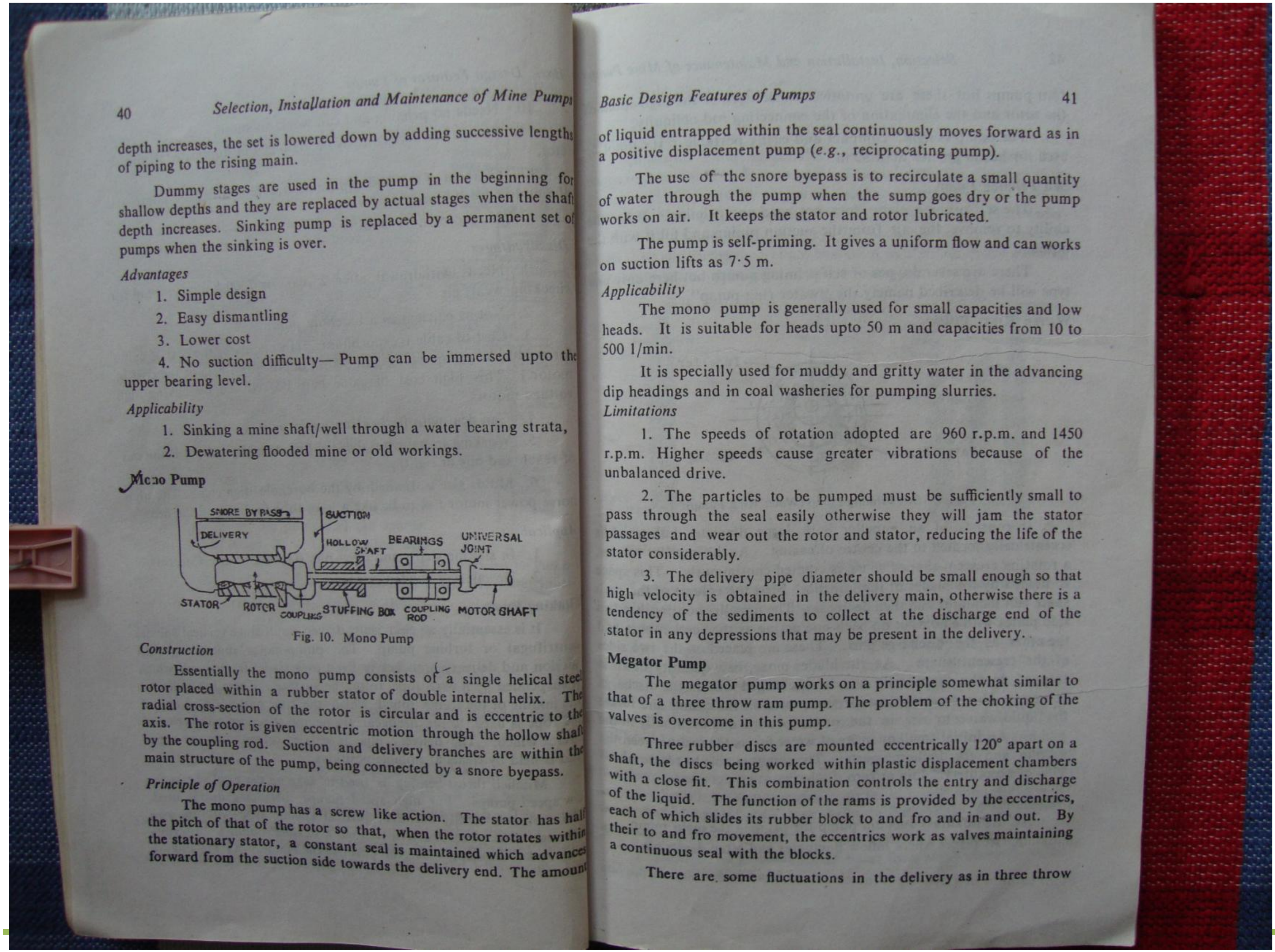
Applicability

1. In sinking shafts and open pits (Ground Water Control),
2. Dewatering flooded mines.

Sinking Pump

It is essentially an electrically driven, multistage vertical spindle centrifugal or turbine pump. The pump-motor unit along with suction and delivery branches is fixed to a girder frame-work which is suspended by a wire rope from the surface. There is a pulley at the middle of the frame round which the rope passes. One end of the rope is fixed to the headgear frame and the other end is wound over a winch. The delivery pipe is carried between the two ropes and is held by cleats at suitable positions.

Mitchell thrust bearing is used to take up the axial thrust for low speed pumps. For high speed pumps, balancing disc is used. The motor is totally enclosed, vertical spindle type with its own bearing. The pump is driven through a flexible coupling. Flexible leads take the supply current down to the motor. As the sinking



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depth increases, the set is lowered down by adding successive lengths of piping to the rising main.

Dummy stages are used in the pump in the beginning for shallow depths and they are replaced by actual stages when the shaft depth increases. Sinking pump is replaced by a permanent set of pumps when the sinking is over.

Advantages

1. Simple design
2. Easy dismantling
3. Lower cost
4. No suction difficulty— Pump can be immersed upto the upper bearing level.

Applicability

1. Sinking a mine shaft/well through a water bearing strata,
2. Dewatering flooded mine or old workings.

Mono Pump

Fig. 10. Mono Pump

Construction

Essentially the mono pump consists of a single helical steel rotor placed within a rubber stator of double internal helix. The radial cross-section of the rotor is circular and is eccentric to the axis. The rotor is given eccentric motion through the hollow shaft by the coupling rod. Suction and delivery branches are within the main structure of the pump, being connected by a snore byepass.

Principle of Operation

The mono pump has a screw like action. The stator has half the pitch of that of the rotor so that, when the rotor rotates within the stationary stator, a constant seal is maintained which advances forward from the suction side towards the delivery end. The amount

Basic Design Features of Pumps 41

of liquid entrapped within the seal continuously moves forward as in a positive displacement pump (*e.g.*, reciprocating pump).

The use of the snore byepass is to recirculate a small quantity of water through the pump when the sump goes dry or the pump works on air. It keeps the stator and rotor lubricated.

The pump is self-priming. It gives a uniform flow and can works on suction lifts as 7·5 m.

Applicability

The mono pump is generally used for small capacities and low heads. It is suitable for heads upto 50 m and capacities from 10 to 500 l/min.

It is specially used for muddy and gritty water in the advancing dip headings and in coal washeries for pumping slurries.

Limitations

1. The speeds of rotation adopted are 960 r.p.m. and 1450 r.p.m. Higher speeds cause greater vibrations because of the unbalanced drive.

2. The particles to be pumped must be sufficiently small to pass through the seal easily otherwise they will jam the stator passages and wear out the rotor and stator, reducing the life of the stator considerably.

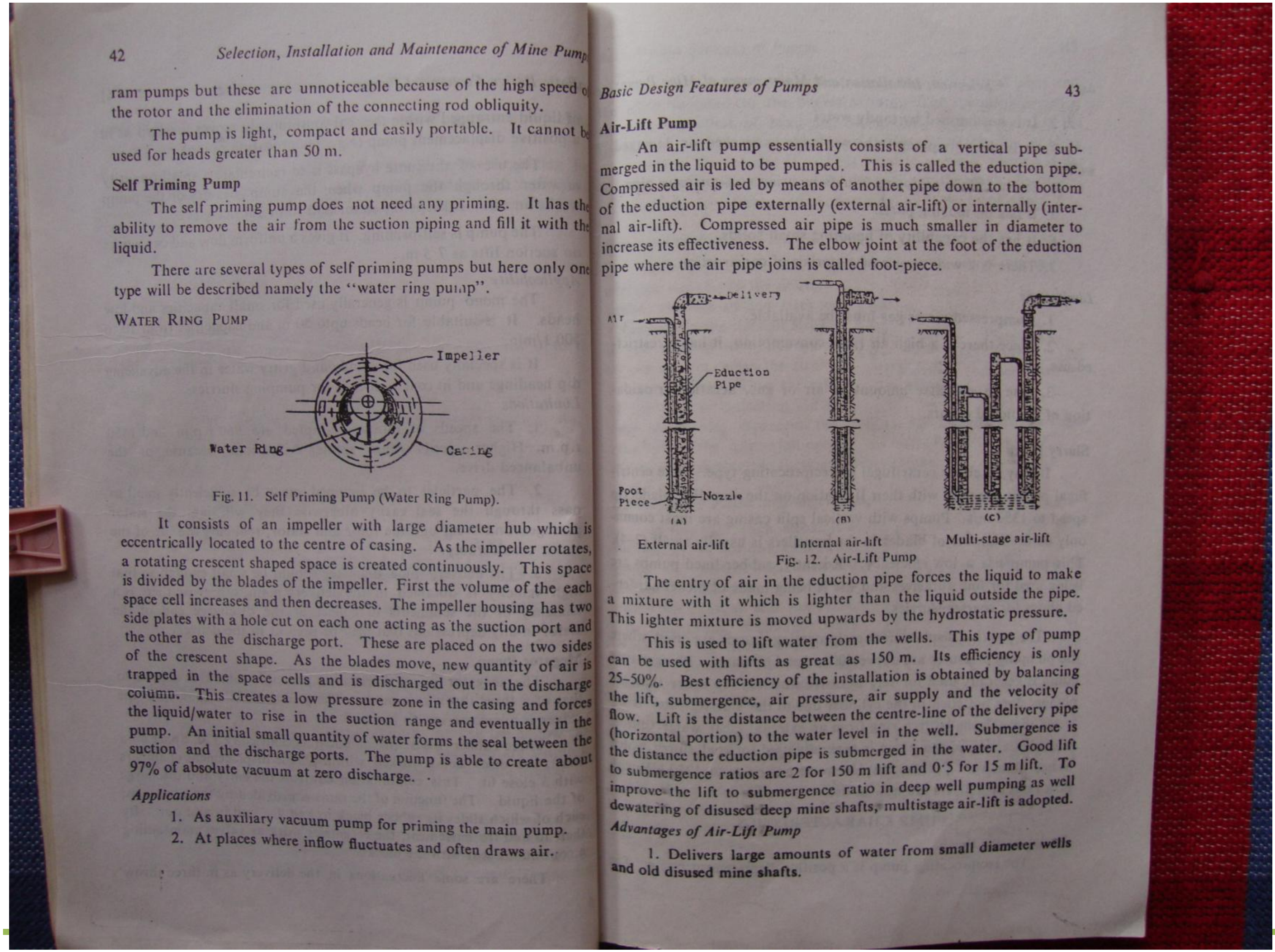
3. The delivery pipe diameter should be small enough so that high velocity is obtained in the delivery main, otherwise there is a tendency of the sediments to collect at the discharge end of the stator in any depressions that may be present in the delivery.

Megator Pump

The megator pump works on a principle somewhat similar to that of a three throw ram pump. The problem of the choking of the valves is overcome in this pump.

Three rubber discs are mounted eccentrically 120° apart on a shaft, the discs being worked within plastic displacement chambers with a close fit. This combination controls the entry and discharge of the liquid. The function of the rams is provided by the eccentrics, each of which slides its rubber block to and fro and in and out. By their to and fro movement, the eccentrics work as valves maintaining a continuous seal with the blocks.

There are some fluctuations in the delivery as in three throw



ram pumps but these are unnoticeable because of the high speed o the rotor and the elimination of the connecting rod obliquity.

The pump is light, compact and easily portable. It cannot b used for heads greater than 50 m.

Self Priming Pump

The self priming pump does not need any priming. It has the ability to remove the air from the suction piping and fill it with the liquid.

There are several types of self priming pumps but here only one type will be described namely the "water ring pump".

WATER RING PUMP

Fig. 11. Self Priming Pump (Water Ring Pump).

It consists of an impeller with large diameter hub which is eccentrically located to the centre of casing. As the impeller rotates, a rotating crescent shaped space is created continuously. This space is divided by the blades of the impeller. First the volume of the each space cell increases and then decreases. The impeller housing has two side plates with a hole cut on each one acting as the suction port and the other as the discharge port. These are placed on the two sides of the crescent shape. As the blades move, new quantity of air is trapped in the space cells and is discharged out in the discharge column. This creates a low pressure zone in the casing and forces the liquid/water to rise in the suction range and eventually in the pump. An initial small quantity of water forms the seal between the suction and the discharge ports. The pump is able to create about 97% of absolute vacuum at zero discharge.

Applications

1. As auxiliary vacuum pump for priming the main pump.
2. At places where inflow fluctuates and often draws air.

Air-Lift Pump

An air-lift pump essentially consists of a vertical pipe submerged in the liquid to be pumped. This is called the eduction pipe. Compressed air is led by means of another pipe down to the bottom of the eduction pipe externally (external air-lift) or internally (internal air-lift). Compressed air pipe is much smaller in diameter to increase its effectiveness. The elbow joint at the foot of the eduction pipe where the air pipe joins is called foot-piece.

External air-lift Internal air-lift Multi-stage air-lift

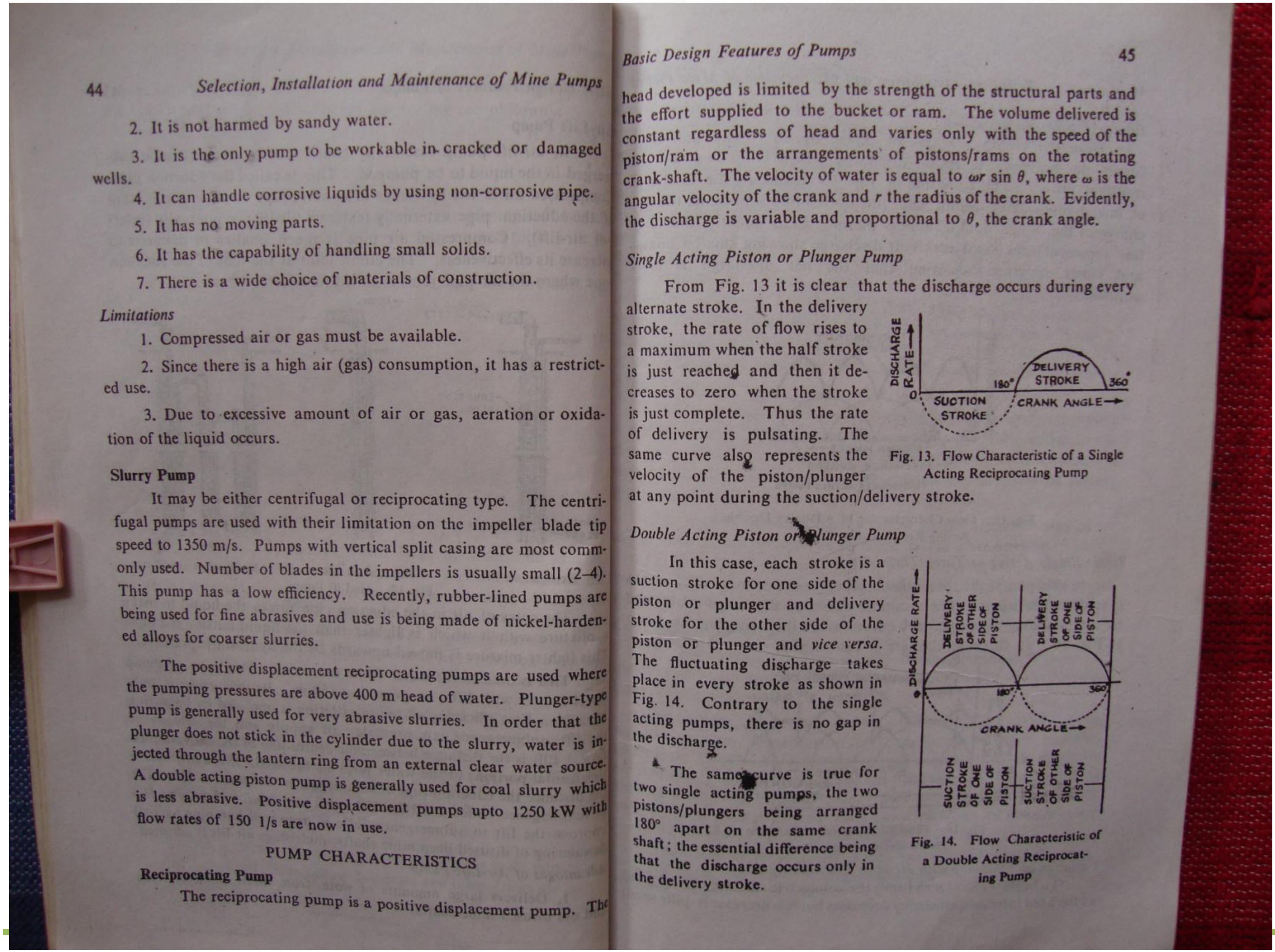
Fig. 12. Air-Lift Pump

The entry of air in the eduction pipe forces the liquid to make a mixture with it which is lighter than the liquid outside the pipe. This lighter mixture is moved upwards by the hydrostatic pressure.

This is used to lift water from the wells. This type of pump can be used with lifts as great as 150 m. Its efficiency is only 25–50%. Best efficiency of the installation is obtained by balancing the lift, submergence, air pressure, air supply and the velocity of flow. Lift is the distance between the centre-line of the delivery pipe (horizontal portion) to the water level in the well. Submergence is the distance the eduction pipe is submerged in the water. Good lift to submergence ratios are 2 for 150 m lift and 0·5 for 15 m lift. To improve the lift to submergence ratio in deep well pumping as well dewatering of disused deep mine shafts, multistage air-lift is adopted.

Advantages of Air-Lift Pump

1. Delivers large amounts of water from small diameter wells and old disused mine shafts.


DISCHARGE RATE
O
DELIVERY STROKE
180°
360°
SUCTION STROKE
CRANK ANGLE
DISCHARGE RATE
DELIVERY STROKE OF OTHER SIDE OF PISTON
DELIVERY STROKE OF ONE SIDE OF PISTON
180°
360
CRANK ANGLE
SUCTION STROKE OF ONE SIDE OF PISTON
SUCTION STROKE OF OTHER SIDE OF PISTON

2. It is not harmed by sandy water.

3. It is the only pump to be workable in cracked or damaged wells.

4. It can handle corrosive liquids by using non-corrosive pipe.

5. It has no moving parts.

6. It has the capability of handling small solids.

7. There is a wide choice of materials of construction.

Limitations

1. Compressed air or gas must be available.

2. Since there is a high air (gas) consumption, it has a restricted use.

3. Due to excessive amount of air or gas, aeration or oxidation of the liquid occurs.

Slurry Pump

It may be either centrifugal or reciprocating type. The centrifugal pumps are used with their limitation on the impeller blade tip speed to 1350 m/s. Pumps with vertical split casing are most commonly used. Number of blades in the impellers is usually small (2–4). This pump has a low efficiency. Recently, rubber-lined pumps are being used for fine abrasives and use is being made of nickel-hardened alloys for coarser slurries.

The positive displacement reciprocating pumps are used where the pumping pressures are above 400 m head of water. Plunger-type pump is generally used for very abrasive slurries. In order that the plunger does not stick in the cylinder due to the slurry, water is injected through the lantern ring from an external clear water source. A double acting piston pump is generally used for coal slurry which is less abrasive. Positive displacement pumps upto 1250 kW with flow rates of 150 l/s are now in use.

PUMP CHARACTERISTICS

Reciprocating Pump

The reciprocating pump is a positive displacement pump. The head developed is limited by the strength of the structural parts and the effort supplied to the bucket or ram. The volume delivered is constant regardless of head and varies only with the speed of the piston/ram or the arrangements of pistons/rams on the rotating crank-shaft. The velocity of water is equal to $\omega r \sin\theta$, where ω is the angular velocity of the crank and r the radius of the crank. Evidently, the discharge is variable and proportional to θ, the crank angle.

Single Acting Piston or Plunger Pump

From Fig. 13 it is clear that the discharge occurs during every alternate stroke. In the delivery stroke, the rate of flow rises to a maximum when the half stroke is just reached and then it decreases to zero when the stroke is just complete. Thus the rate of delivery is pulsating. The same curve also represents the velocity of the piston/plunger at any point during the suction/delivery stroke.

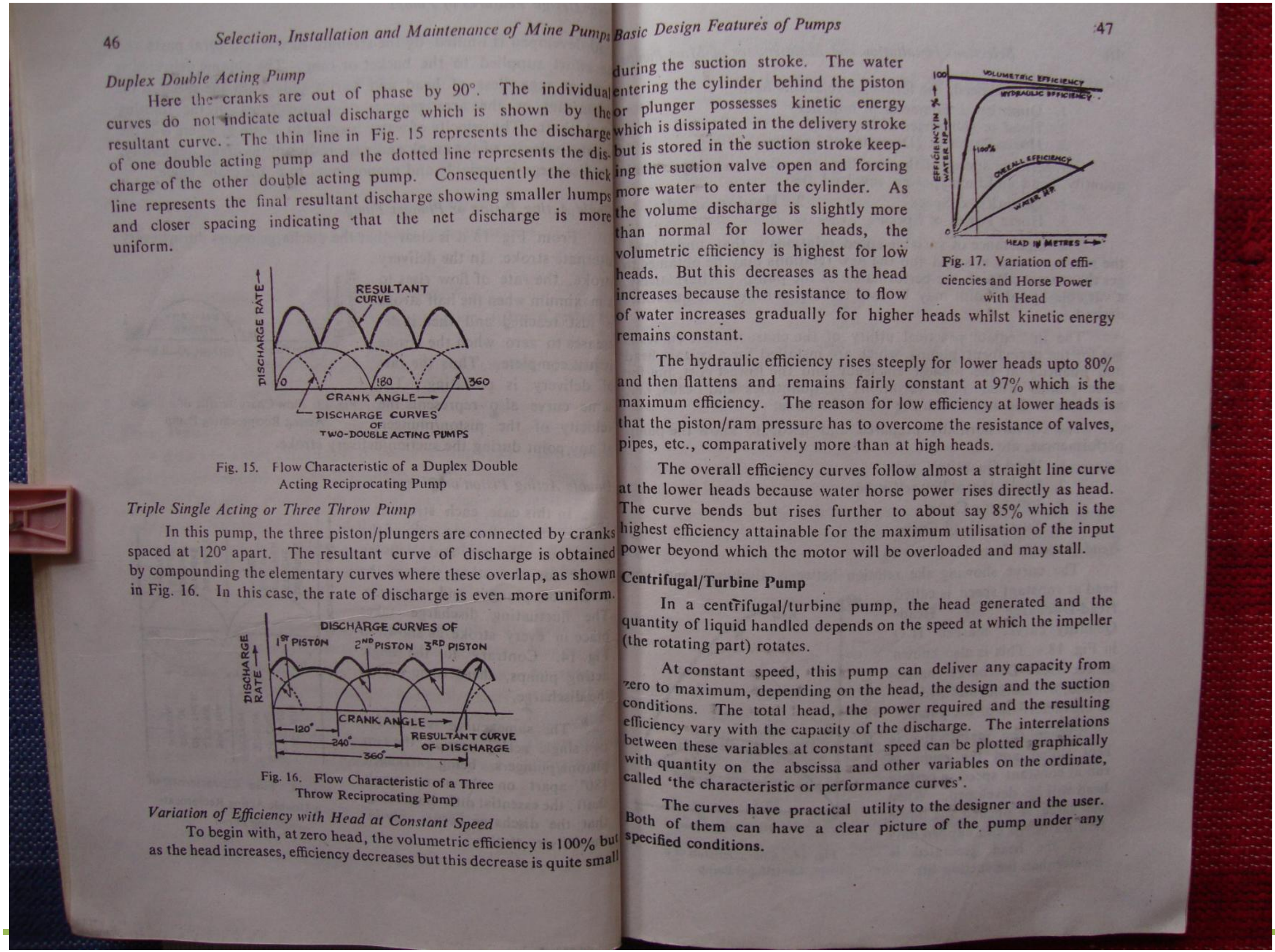
Fig. 13. Flow Characteristic of a Single Acting Reciprocating Pump

Double Acting Piston or Plunger Pump

In this case, each stroke is a suction stroke for one side of the piston or plunger and delivery stroke for the other side of the piston or plunger and *vice versa*. The fluctuating discharge takes place in every stroke as shown in Fig. 14. Contrary to the single acting pumps, there is no gap in the discharge.

The same curve is true for two single acting pumps, the two pistons/plungers being arranged 180° apart on the same crank shaft; the essential difference being that the discharge occurs only in the delivery stroke.

Fig. 14. Flow Characteristic of a Double Acting Reciprocating Pump



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Duplex Double Acting Pump

Here the cranks are out of phase by 90°. The individual curves do not indicate actual discharge which is shown by the resultant curve. The thin line in Fig. 15 represents the discharge of one double acting pump and the dotted line represents the discharge of the other double acting pump. Consequently the thick line represents the final resultant discharge showing smaller humps and closer spacing indicating that the net discharge is more uniform.

Fig. 15. Flow Characteristic of a Duplex Double Acting Reciprocating Pump

Triple Single Acting or Three Throw Pump

In this pump, the three piston/plungers are connected by cranks spaced at 120° apart. The resultant curve of discharge is obtained by compounding the elementary curves where these overlap, as shown in Fig. 16. In this case, the rate of discharge is even more uniform.

Fig. 16. Flow Characteristic of a Three Throw Reciprocating Pump

Variation of Efficiency with Head at Constant Speed

To begin with, at zero head, the volumetric efficiency is 100% but as the head increases, efficiency decreases but this decrease is quite small

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during the suction stroke. The water entering the cylinder behind the piston or plunger possesses kinetic energy which is dissipated in the delivery stroke but is stored in the suction stroke keeping the suction valve open and forcing more water to enter the cylinder. As the volume discharge is slightly more than normal for lower heads, the volumetric efficiency is highest for low heads. But this decreases as the head increases because the resistance to flow of water increases gradually for higher heads whilst kinetic energy remains constant.

Fig. 17. Variation of efficiencies and Horse Power with Head

The hydraulic efficiency rises steeply for lower heads upto 80% and then flattens and remains fairly constant at 97% which is the maximum efficiency. The reason for low efficiency at lower heads is that the piston/ram pressure has to overcome the resistance of valves, pipes, etc., comparatively more than at high heads.

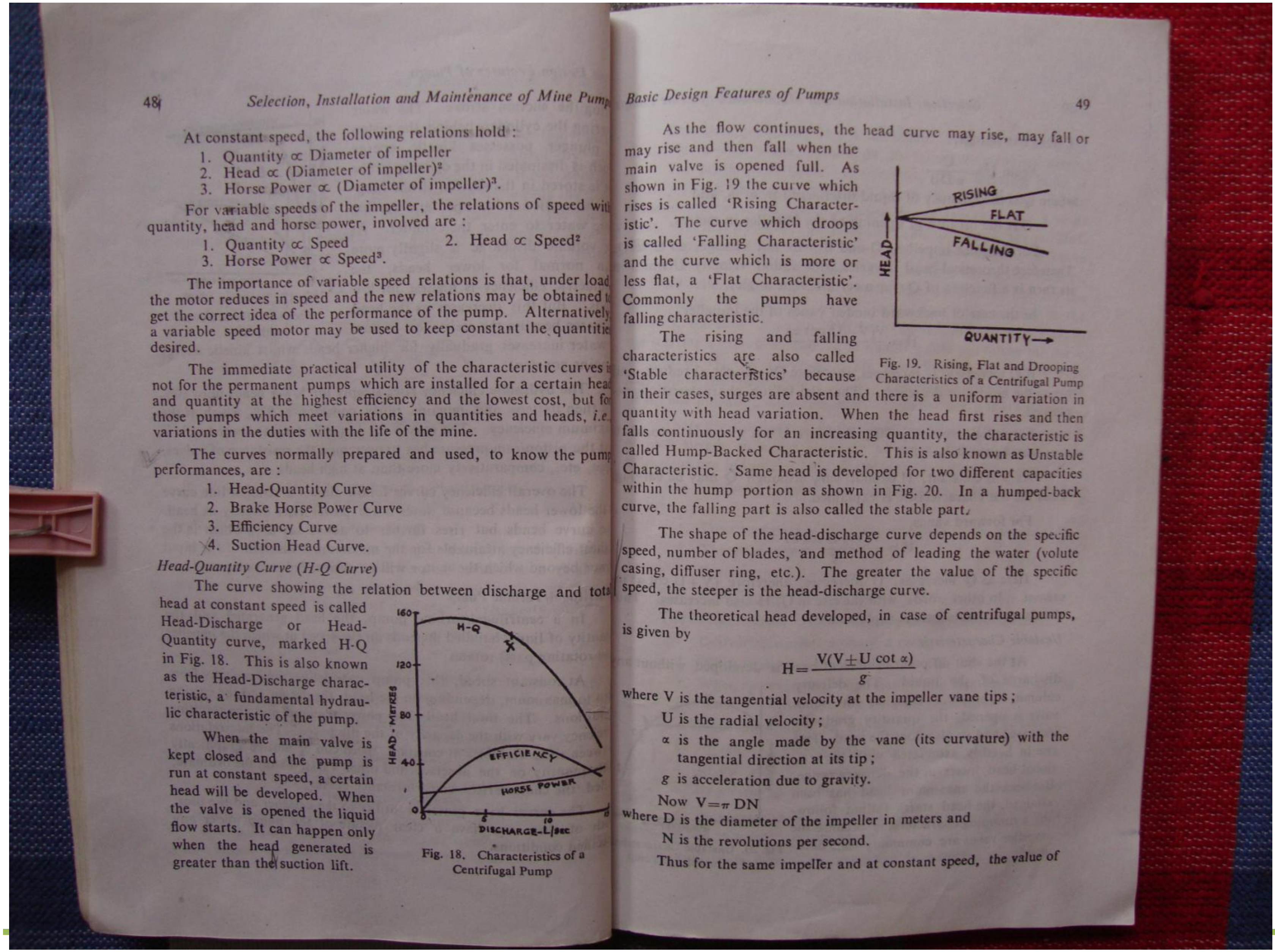
The overall efficiency curves follow almost a straight line curve at the lower heads because water horse power rises directly as head. The curve bends but rises further to about say 85% which is the highest efficiency attainable for the maximum utilisation of the input power beyond which the motor will be overloaded and may stall.

Centrifugal/Turbine Pump

In a centrifugal/turbine pump, the head generated and the quantity of liquid handled depends on the speed at which the impeller (the rotating part) rotates.

At constant speed, this pump can deliver any capacity from zero to maximum, depending on the head, the design and the suction conditions. The total head, the power required and the resulting efficiency vary with the capacity of the discharge. The interrelations between these variables at constant speed can be plotted graphically with quantity on the abscissa and other variables on the ordinate, called 'the characteristic or performance curves'.

The curves have practical utility to the designer and the user. Both of them can have a clear picture of the pump under any specified conditions.



At constant speed, the following relations hold :

1. Quantity ∝ Diameter of impeller
2. Head ∝ (Diameter of impeller)^2
3. Horse Power ∝ (Diameter of impeller)^3.

For variable speeds of the impeller, the relations of speed wit quantity, head and horse power, involved are :

1. Quantity ∝ Speed
2. Head ∝ Speed^2
3. Horse Power ∝ Speed^3.

The importance of variable speed relations is that, under load the motor reduces in speed and the new relations may be obtained t get the correct idea of the performance of the pump. Alternativel a variable speed motor may be used to keep constant the quantitie desired.

The immediate practical utility of the characteristic curves i not for the permanent pumps which are installed for a certain hea and quantity at the highest efficiency and the lowest cost, but fo those pumps which meet variations in quantities and heads, *i.e* variations in the duties with the life of the mine.

The curves normally prepared and used, to know the pum performances, are :

1. Head-Quantity Curve
2. Brake Horse Power Curve
3. Efficiency Curve
4. Suction Head Curve.

Head-Quantity Curve (H-Q Curve)

The curve showing the relation between discharge and tota head at constant speed is called Head-Discharge or Head-Quantity curve, marked H-Q in Fig. 18. This is also known as the Head-Discharge characteristic, a fundamental hydraulic characteristic of the pump.

When the main valve is kept closed and the pump is run at constant speed, a certain head will be developed. When the valve is opened the liquid flow starts. It can happen only when the head generated is greater than the suction lift.

Fig. 18. Characteristics of a Centrifugal Pump

As the flow continues, the head curve may rise, may fall or may rise and then fall when the main valve is opened full. As shown in Fig. 19 the curve which rises is called 'Rising Characteristic'. The curve which droops is called 'Falling Characteristic' and the curve which is more or less flat, a 'Flat Characteristic'. Commonly the pumps have falling characteristic.

The rising and falling characteristics are also called 'Stable characteristics' because in their cases, surges are absent and there is a uniform variation in quantity with head variation. When the head first rises and then falls continuously for an increasing quantity, the characteristic is called Hump-Backed Characteristic. This is also known as Unstable Characteristic. Same head is developed for two different capacities within the hump portion as shown in Fig. 20. In a humped-back curve, the falling part is also called the stable part.

Fig. 19. Rising, Flat and Drooping Characteristics of a Centrifugal Pump

The shape of the head-discharge curve depends on the specific speed, number of blades, and method of leading the water (volute casing, diffuser ring, etc.). The greater the value of the specific speed, the steeper is the head-discharge curve.

The theoretical head developed, in case of centrifugal pumps, is given by

$$H=\frac{V(V\pm U\cot\alpha)}{g}$$

where V is the tangential velocity at the impeller vane tips ;

U is the radial velocity ;

α is the angle made by the vane (its curvature) with the tangential direction at its tip ;

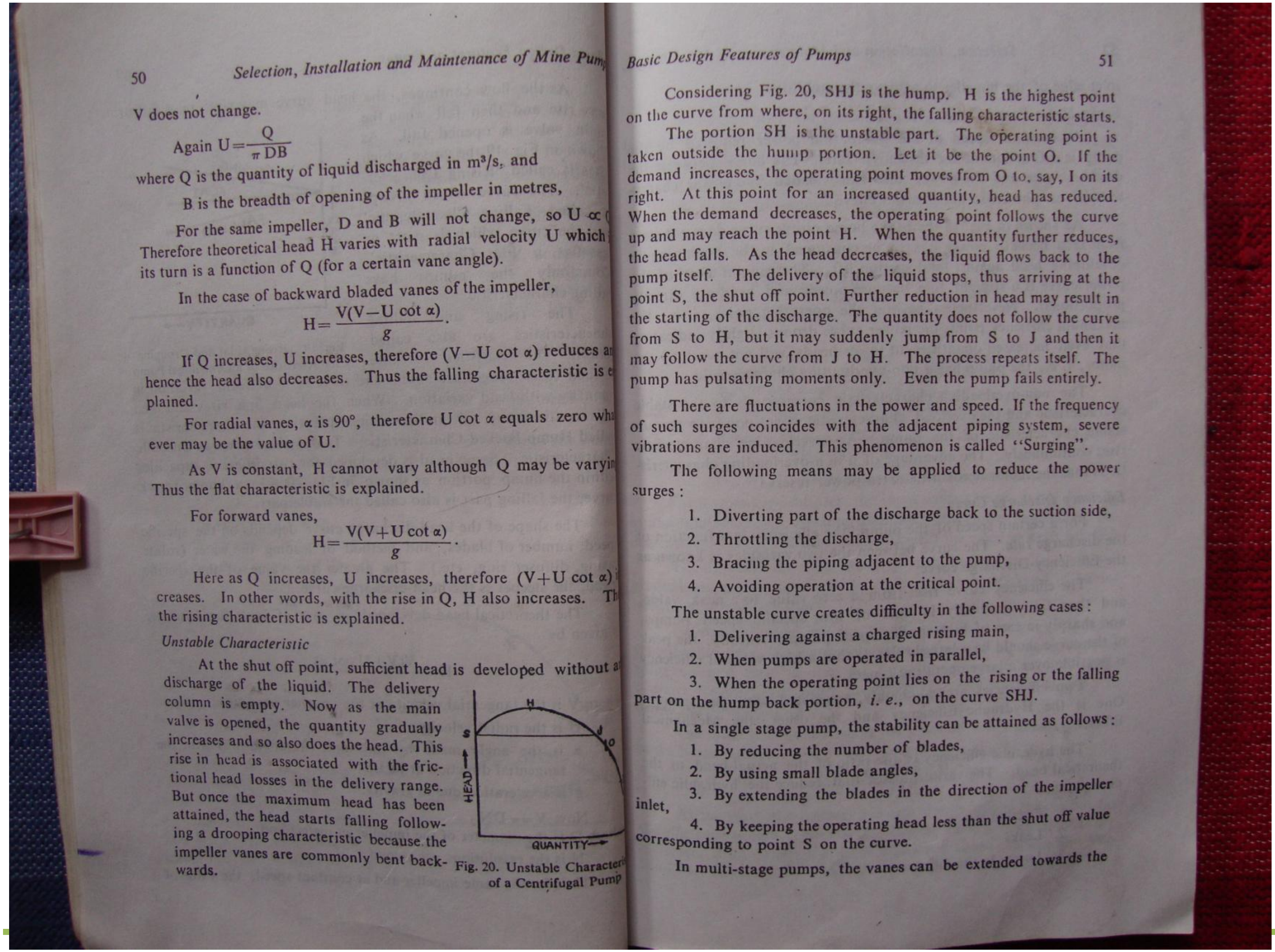
g is acceleration due to gravity.

Now $V=\pi DN$

where D is the diameter of the impeller in meters and

N is the revolutions per second.

Thus for the same impeller and at constant speed, the value of



V does not change.

Again $U = \frac{Q}{\pi DB}$

where Q is the quantity of liquid discharged in m^3/s, and

B is the breadth of opening of the impeller in metres,

For the same impeller, D and B will not change, so $U \propto$ Therefore theoretical head H varies with radial velocity U which its turn is a function of Q (for a certain vane angle).

In the case of backward bladed vanes of the impeller,

$$H = \frac{V(V - U\cot\alpha)}{g}.$$

If Q increases, U increases, therefore $(V - U\cot\alpha)$ reduces a hence the head also decreases. Thus the falling characteristic is e plained.

For radial vanes, α is 90°, therefore $U\cot\alpha$ equals zero wh ever may be the value of U.

As V is constant, H cannot vary although Q may be varyi Thus the flat characteristic is explained.

For forward vanes,

$$H = \frac{V(V + U\cot\alpha)}{g}.$$

Here as Q increases, U increases, therefore $(V + U\cot\alpha)$ creases. In other words, with the rise in Q, H also increases. Th the rising characteristic is explained.

Unstable Characteristic

At the shut off point, sufficient head is developed without a discharge of the liquid. The delivery column is empty. Now as the main valve is opened, the quantity gradually increases and so also does the head. This rise in head is associated with the frictional head losses in the delivery range. But once the maximum head has been attained, the head starts falling following a drooping characteristic because the impeller vanes are commonly bent backwards.

Fig. 20. Unstable Characteri of a Centrifugal Pump

Considering Fig. 20, SHJ is the hump. H is the highest point on the curve from where, on its right, the falling characteristic starts. The portion SH is the unstable part. The operating point is taken outside the hump portion. Let it be the point O. If the demand increases, the operating point moves from O to, say, I on its right. At this point for an increased quantity, head has reduced. When the demand decreases, the operating point follows the curve up and may reach the point H. When the quantity further reduces, the head falls. As the head decreases, the liquid flows back to the pump itself. The delivery of the liquid stops, thus arriving at the point S, the shut off point. Further reduction in head may result in the starting of the discharge. The quantity does not follow the curve from S to H, but it may suddenly jump from S to J and then it may follow the curve from J to H. The process repeats itself. The pump has pulsating moments only. Even the pump fails entirely.

There are fluctuations in the power and speed. If the frequency of such surges coincides with the adjacent piping system, severe vibrations are induced. This phenomenon is called "Surging".

The following means may be applied to reduce the power surges :

1. Diverting part of the discharge back to the suction side,
2. Throttling the discharge,
3. Bracing the piping adjacent to the pump,
4. Avoiding operation at the critical point.

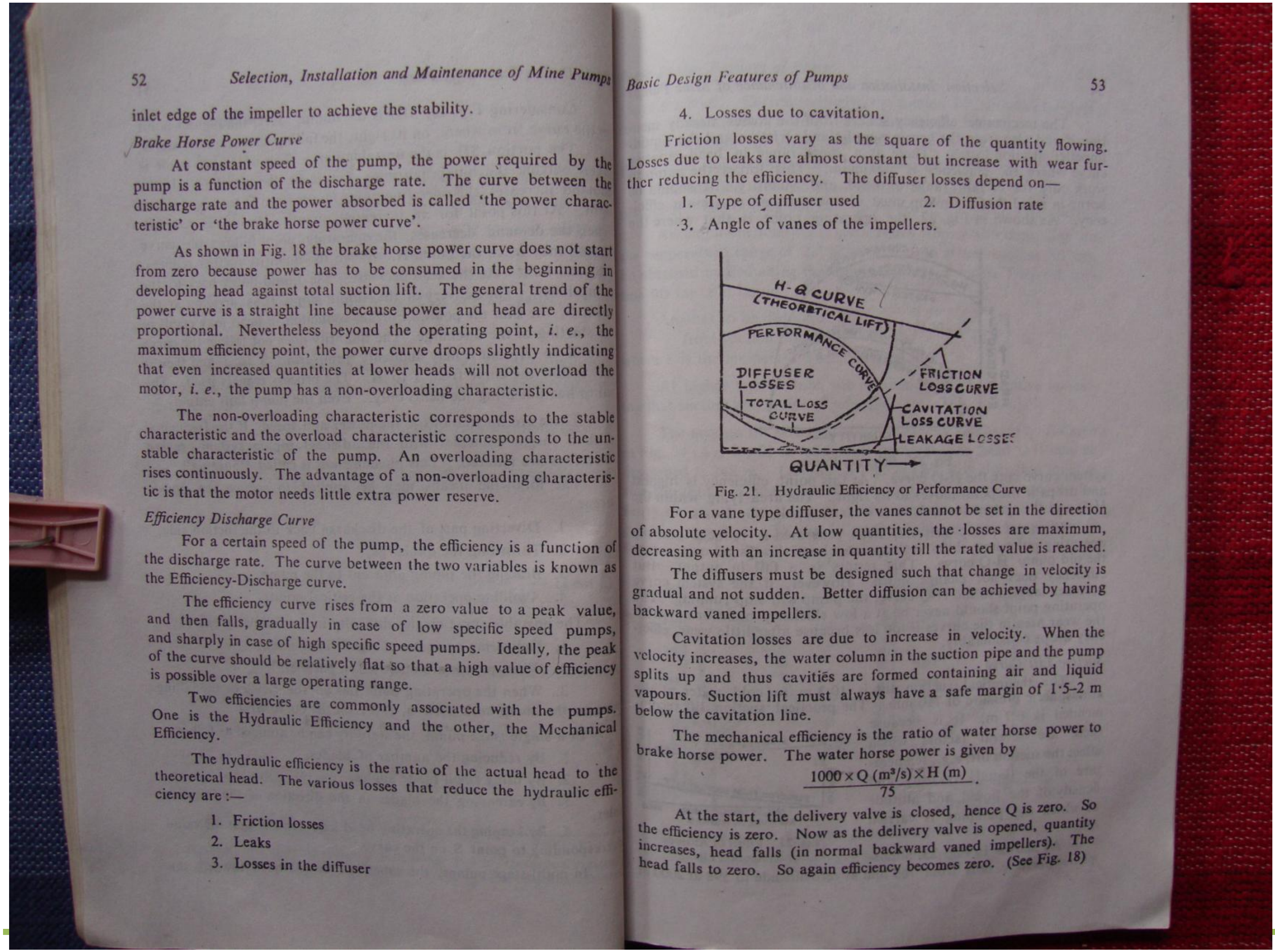
The unstable curve creates difficulty in the following cases :

1. Delivering against a charged rising main,
2. When pumps are operated in parallel,
3. When the operating point lies on the rising or the falling part on the hump back portion, *i. e.*, on the curve SHJ.

In a single stage pump, the stability can be attained as follows :

1. By reducing the number of blades,
2. By using small blade angles,
3. By extending the blades in the direction of the impeller inlet,
4. By keeping the operating head less than the shut off value corresponding to point S on the curve.

In multi-stage pumps, the vanes can be extended towards the



inlet edge of the impeller to achieve the stability.

Brake Horse Power Curve

At constant speed of the pump, the power required by the pump is a function of the discharge rate. The curve between the discharge rate and the power absorbed is called 'the power characteristic' or 'the brake horse power curve'.

As shown in Fig. 18 the brake horse power curve does not start from zero because power has to be consumed in the beginning in developing head against total suction lift. The general trend of the power curve is a straight line because power and head are directly proportional. Nevertheless beyond the operating point, *i. e.*, the maximum efficiency point, the power curve droops slightly indicating that even increased quantities at lower heads will not overload the motor, *i. e.*, the pump has a non-overloading characteristic.

The non-overloading characteristic corresponds to the stable characteristic and the overload characteristic corresponds to the unstable characteristic of the pump. An overloading characteristic rises continuously. The advantage of a non-overloading characteristic is that the motor needs little extra power reserve.

Efficiency Discharge Curve

For a certain speed of the pump, the efficiency is a function of the discharge rate. The curve between the two variables is known as the Efficiency-Discharge curve.

The efficiency curve rises from a zero value to a peak value, and then falls, gradually in case of low specific speed pumps, and sharply in case of high specific speed pumps. Ideally, the peak of the curve should be relatively flat so that a high value of efficiency is possible over a large operating range.

Two efficiencies are commonly associated with the pumps. One is the Hydraulic Efficiency and the other, the Mechanical Efficiency.

The hydraulic efficiency is the ratio of the actual head to the theoretical head. The various losses that reduce the hydraulic efficiency are :—

1. Friction losses
2. Leaks
3. Losses in the diffuser

4. Losses due to cavitation.

Friction losses vary as the square of the quantity flowing. Losses due to leaks are almost constant but increase with wear further reducing the efficiency. The diffuser losses depend on—

1. Type of diffuser used   2. Diffusion rate
3. Angle of vanes of the impellers.

Fig. 21. Hydraulic Efficiency or Performance Curve

For a vane type diffuser, the vanes cannot be set in the direction of absolute velocity. At low quantities, the losses are maximum, decreasing with an increase in quantity till the rated value is reached.

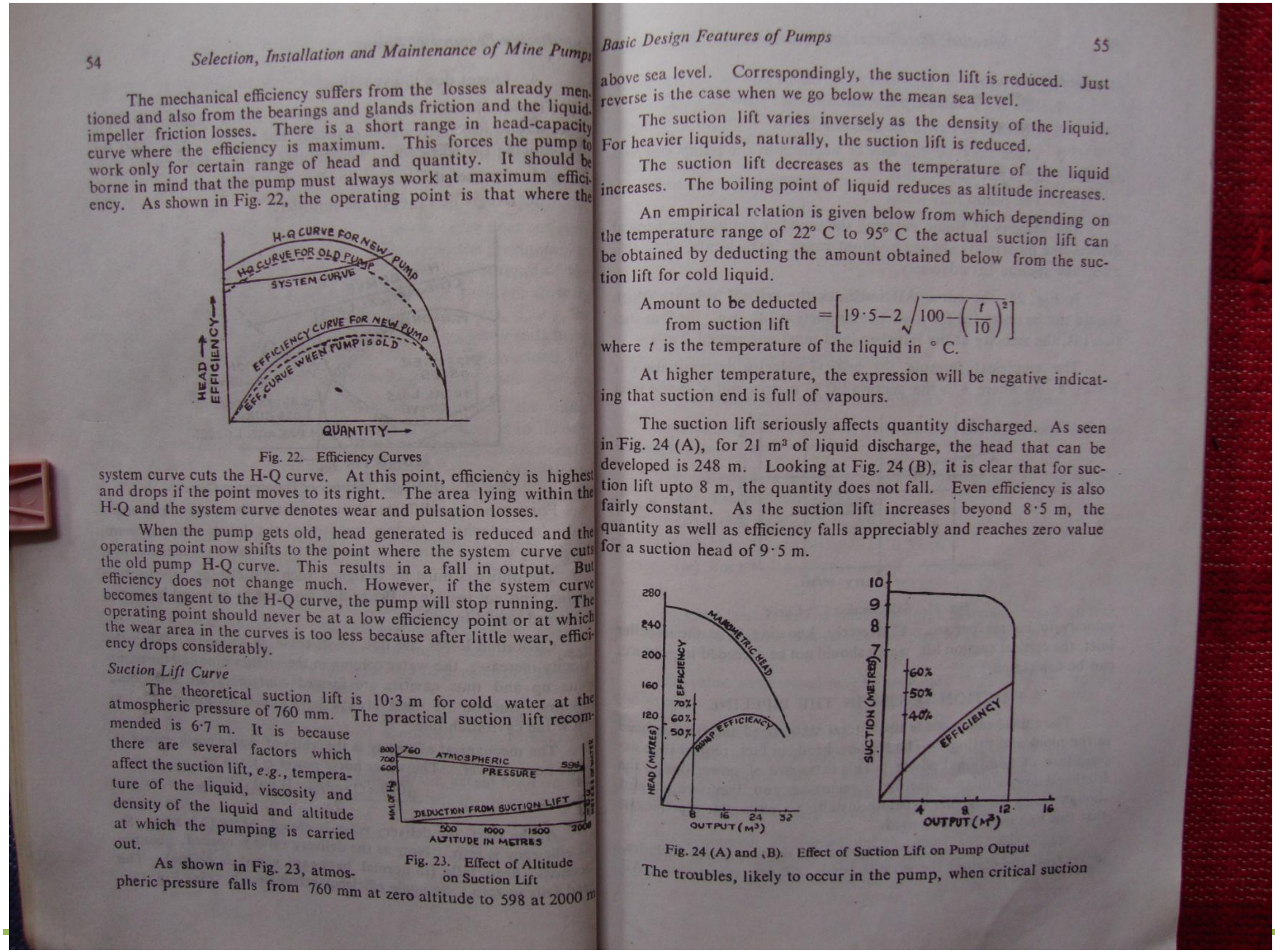
The diffusers must be designed such that change in velocity is gradual and not sudden. Better diffusion can be achieved by having backward vaned impellers.

Cavitation losses are due to increase in velocity. When the velocity increases, the water column in the suction pipe and the pump splits up and thus cavities are formed containing air and liquid vapours. Suction lift must always have a safe margin of 1·5–2 m below the cavitation line.

The mechanical efficiency is the ratio of water horse power to brake horse power. The water horse power is given by

$$\frac{1000 \times Q\,(m^3/s) \times H\,(m)}{75}.$$

At the start, the delivery valve is closed, hence Q is zero. So the efficiency is zero. Now as the delivery valve is opened, quantity increases, head falls (in normal backward vaned impellers). The head falls to zero. So again efficiency becomes zero. (See Fig. 18)



The mechanical efficiency suffers from the losses already mentioned and also from the bearings and glands friction and the liquid impeller friction losses. There is a short range in head-capacity curve where the efficiency is maximum. This forces the pump to work only for certain range of head and quantity. It should be borne in mind that the pump must always work at maximum efficiency. As shown in Fig. 22, the operating point is that where the system curve cuts the H-Q curve. At this point, efficiency is highest and drops if the point moves to its right. The area lying within the H-Q and the system curve denotes wear and pulsation losses.

H-Q CURVE FOR NEW PUMP
H-Q CURVE FOR OLD PUMP
SYSTEM CURVE
EFFICIENCY CURVE FOR NEW PUMP
EFF. CURVE WHEN PUMP IS OLD
HEAD → EFFICIENCY
QUANTITY→

Fig. 22. Efficiency Curves

When the pump gets old, head generated is reduced and the operating point now shifts to the point where the system curve cuts the old pump H-Q curve. This results in a fall in output. But efficiency does not change much. However, if the system curve becomes tangent to the H-Q curve, the pump will stop running. The operating point should never be at a low efficiency point or at which the wear area in the curves is too less because after little wear, efficiency drops considerably.

Suction Lift Curve

The theoretical suction lift is 10·3 m for cold water at the atmospheric pressure of 760 mm. The practical suction lift recommended is 6·7 m. It is because there are several factors which affect the suction lift, *e.g.*, temperature of the liquid, viscosity and density of the liquid and altitude at which the pumping is carried out.

As shown in Fig. 23, atmospheric pressure falls from 760 mm at zero altitude to 598 at 2000 m above sea level. Correspondingly, the suction lift is reduced. Just reverse is the case when we go below the mean sea level.

800
700
600
760
ATMOSPHERIC PRESSURE
598
MM. OF Hg
DEDUCTION FROM SUCTION LIFT
500
1000
1500
2000
ALTITUDE IN METRES

Fig. 23. Effect of Altitude on Suction Lift

The suction lift varies inversely as the density of the liquid. For heavier liquids, naturally, the suction lift is reduced.

The suction lift decreases as the temperature of the liquid increases. The boiling point of liquid reduces as altitude increases.

An empirical relation is given below from which depending on the temperature range of 22° C to 95° C the actual suction lift can be obtained by deducting the amount obtained below from the suction lift for cold liquid.

$$\text{Amount to be deducted from suction lift} = \left[19{\cdot}5 - 2\sqrt{100 - \left(\frac{t}{10}\right)^2}\right]$$

where t is the temperature of the liquid in ° C.

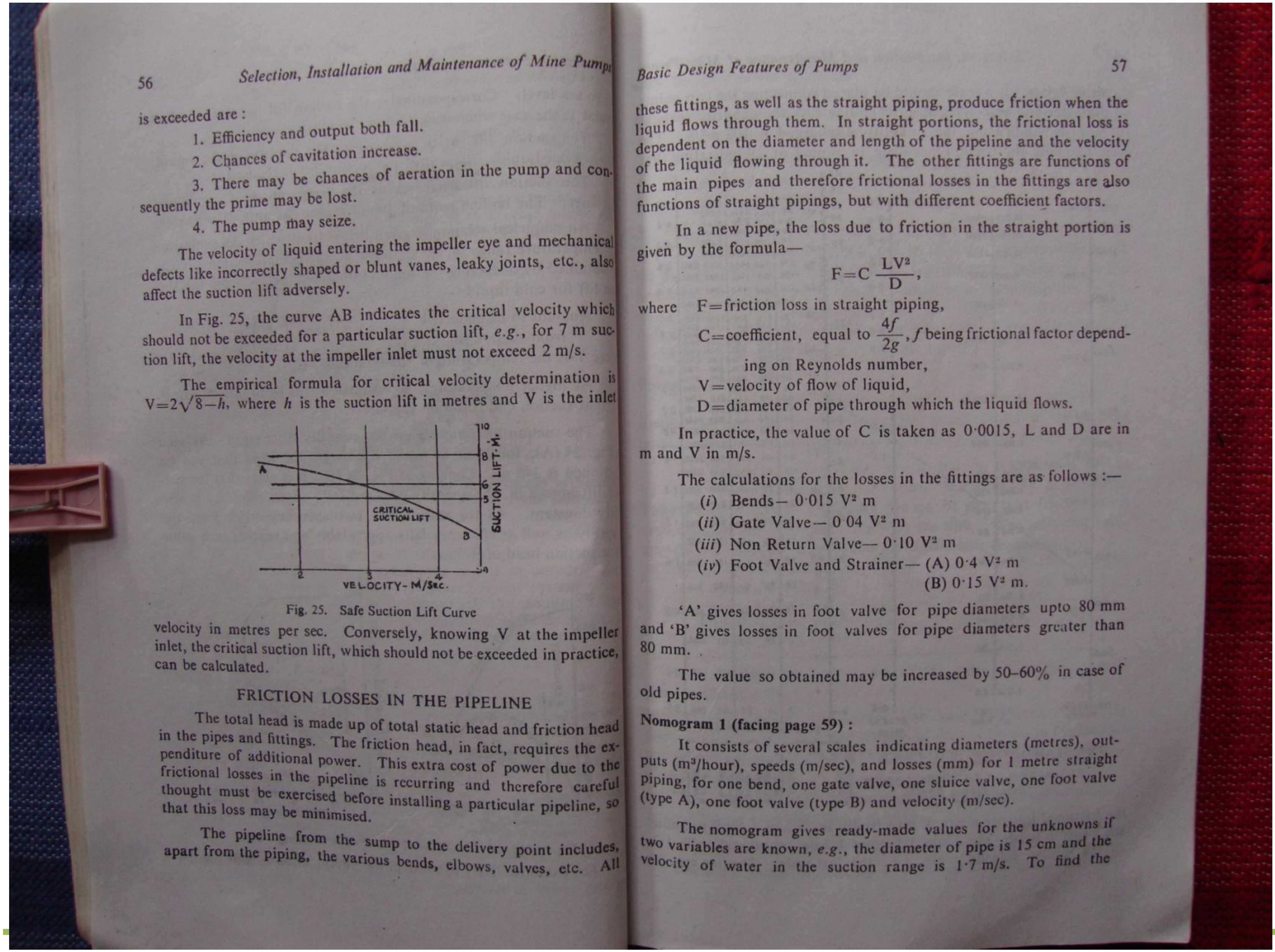
At higher temperature, the expression will be negative indicating that suction end is full of vapours.

The suction lift seriously affects quantity discharged. As seen in Fig. 24 (A), for 21 m^3 of liquid discharge, the head that can be developed is 248 m. Looking at Fig. 24 (B), it is clear that for suction lift upto 8 m, the quantity does not fall. Even efficiency is also fairly constant. As the suction lift increases beyond 8·5 m, the quantity as well as efficiency falls appreciably and reaches zero value for a suction head of 9·5 m.

280
240
200
160
120
HEAD (METRES)
EFFICIENCY
70%
60%
50%
MANOMETRIC HEAD
PUMP EFFICIENCY
8
16
24
32
OUTPUT (M³)
10
9
8
7
SUCTION (METRES)
60%
50%
40%
EFFICIENCY
4
8
12
16
OUTPUT (M³)

Fig. 24 (A) and (B). Effect of Suction Lift on Pump Output

The troubles, likely to occur in the pump, when critical suction


A
B
CRITICAL SUCTION LIFT
2
3
4
VELOCITY-M/SEC.
10
8
6
5
4
SUCTION LIFT-M.

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is exceeded are :

1. Efficiency and output both fall.
2. Chances of cavitation increase.
3. There may be chances of aeration in the pump and consequently the prime may be lost.
4. The pump may seize.

The velocity of liquid entering the impeller eye and mechanical defects like incorrectly shaped or blunt vanes, leaky joints, etc., also affect the suction lift adversely.

In Fig. 25, the curve AB indicates the critical velocity which should not be exceeded for a particular suction lift, *e.g.*, for 7 m suction lift, the velocity at the impeller inlet must not exceed 2 m/s.

The empirical formula for critical velocity determination is $V=2\sqrt{8-h}$, where h is the suction lift in metres and V is the inlet velocity in metres per sec. Conversely, knowing V at the impeller inlet, the critical suction lift, which should not be exceeded in practice, can be calculated.

Fig. 25. Safe Suction Lift Curve

FRICTION LOSSES IN THE PIPELINE

The total head is made up of total static head and friction head in the pipes and fittings. The friction head, in fact, requires the expenditure of additional power. This extra cost of power due to the frictional losses in the pipeline is recurring and therefore careful thought must be exercised before installing a particular pipeline, so that this loss may be minimised.

The pipeline from the sump to the delivery point includes, apart from the piping, the various bends, elbows, valves, etc. All

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these fittings, as well as the straight piping, produce friction when the liquid flows through them. In straight portions, the frictional loss is dependent on the diameter and length of the pipeline and the velocity of the liquid flowing through it. The other fittings are functions of the main pipes and therefore frictional losses in the fittings are also functions of straight pipings, but with different coefficient factors.

In a new pipe, the loss due to friction in the straight portion is given by the formula—

$$F=C\,\frac{LV^2}{D},$$

where F = friction loss in straight piping,
C = coefficient, equal to $\frac{4f}{2g}$, f being frictional factor depending on Reynolds number,
V = velocity of flow of liquid,
D = diameter of pipe through which the liquid flows.

In practice, the value of C is taken as 0·0015, L and D are in m and V in m/s.

The calculations for the losses in the fittings are as follows :—

(*i*) Bends— 0·015 V^2 m
(*ii*) Gate Valve— 0·04 V^2 m
(*iii*) Non Return Valve— 0·10 V^2 m
(*iv*) Foot Valve and Strainer— (A) 0·4 V^2 m
(B) 0·15 V^2 m.

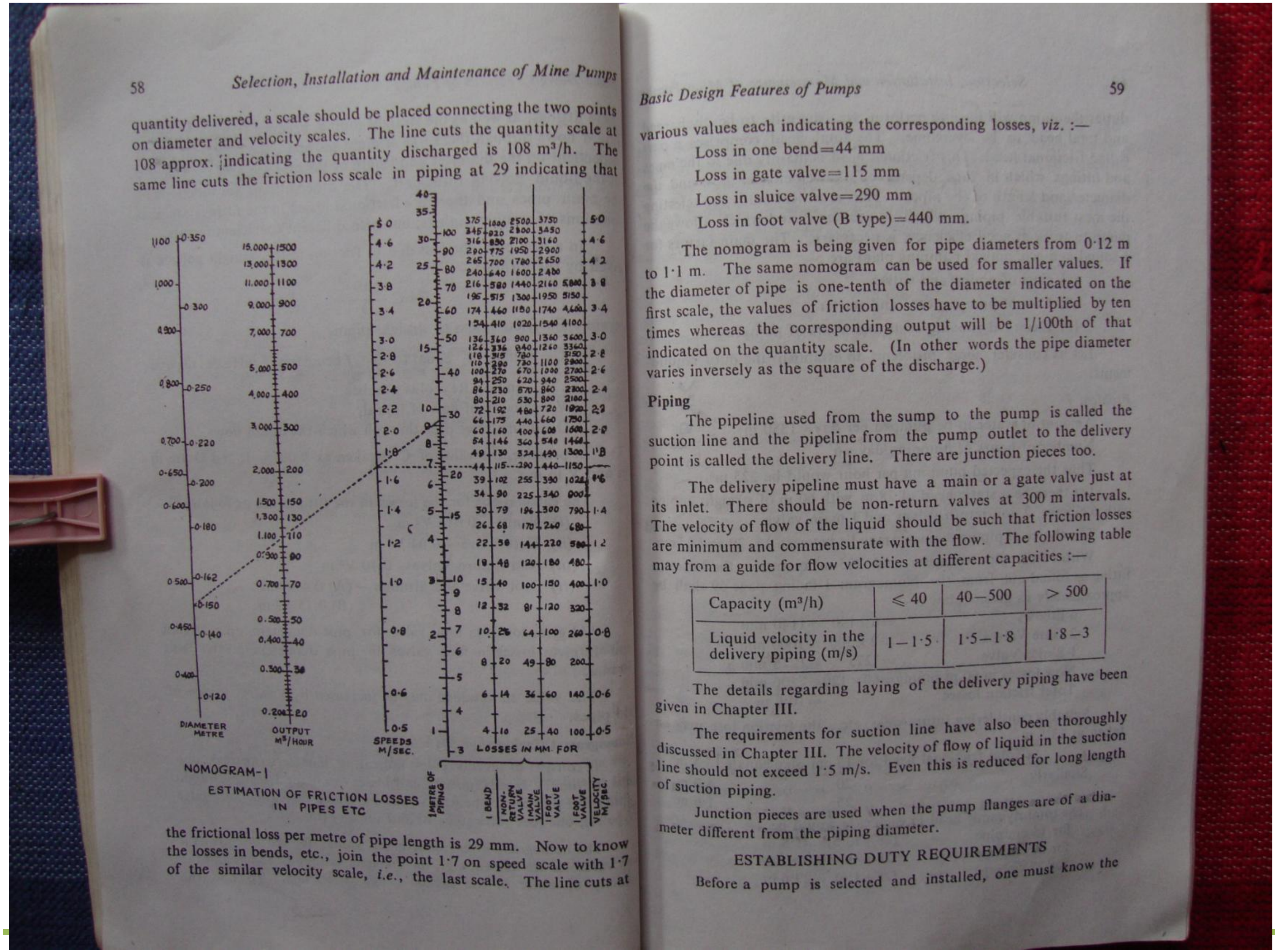
'A' gives losses in foot valve for pipe diameters upto 80 mm and 'B' gives losses in foot valves for pipe diameters greater than 80 mm.

The value so obtained may be increased by 50–60% in case of old pipes.

Nomogram 1 (facing page 59) :

It consists of several scales indicating diameters (metres), outputs (m^3/hour), speeds (m/sec), and losses (mm) for 1 metre straight piping, for one bend, one gate valve, one sluice valve, one foot valve (type A), one foot valve (type B) and velocity (m/sec).

The nomogram gives ready-made values for the unknowns if two variables are known, *e.g.*, the diameter of pipe is 15 cm and the velocity of water in the suction range is 1·7 m/s. To find the



quantity delivered, a scale should be placed connecting the two points on diameter and velocity scales. The line cuts the quantity scale at 108 approx. indicating the quantity discharged is 108 m³/h. The same line cuts the friction loss scale in piping at 29 indicating that

DIAMETER METRE
OUTPUT M³/HOUR
SPEEDS M/SEC.
LOSSES IN MM. FOR
1 METRE OF PIPING
1 BEND
1 NON-RETURN VALVE
1 MAIN VALVE
1 FOOT VALVE
1 FOOT VALVE
VELOCITY M/SEC.

NOMOGRAM-1

ESTIMATION OF FRICTION LOSSES IN PIPES ETC

the frictional loss per metre of pipe length is 29 mm. Now to know the losses in bends, etc., join the point 1·7 on speed scale with 1·7 of the similar velocity scale, *i.e.*, the last scale. The line cuts at

various values each indicating the corresponding losses, *viz.* :—

Loss in one bend=44 mm
Loss in gate valve=115 mm
Loss in sluice valve=290 mm
Loss in foot valve (B type)=440 mm.

The nomogram is being given for pipe diameters from 0·12 m to 1·1 m. The same nomogram can be used for smaller values. If the diameter of pipe is one-tenth of the diameter indicated on the first scale, the values of friction losses have to be multiplied by ten times whereas the corresponding output will be 1/100th of that indicated on the quantity scale. (In other words the pipe diameter varies inversely as the square of the discharge.)

Piping

The pipeline used from the sump to the pump is called the suction line and the pipeline from the pump outlet to the delivery point is called the delivery line. There are junction pieces too.

The delivery pipeline must have a main or a gate valve just at its inlet. There should be non-return valves at 300 m intervals. The velocity of flow of the liquid should be such that friction losses are minimum and commensurate with the flow. The following table may from a guide for flow velocities at different capacities :—

Capacity (m³/h)	≤ 40	40—500	> 500
Liquid velocity in the delivery piping (m/s)	1—1·5	1·5—1·8	1·8—3

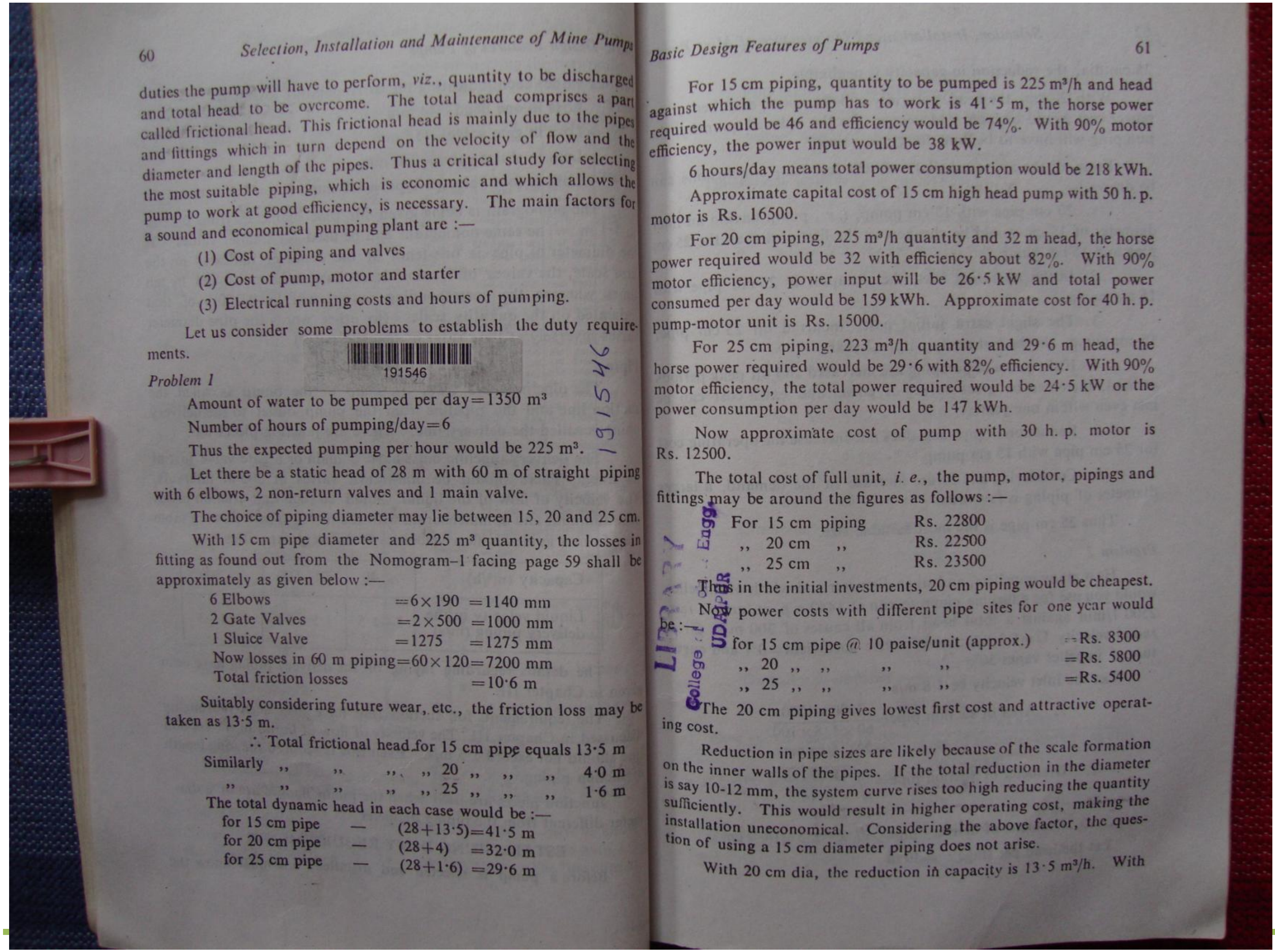
The details regarding laying of the delivery piping have been given in Chapter III.

The requirements for suction line have also been thoroughly discussed in Chapter III. The velocity of flow of liquid in the suction line should not exceed 1·5 m/s. Even this is reduced for long length of suction piping.

Junction pieces are used when the pump flanges are of a diameter different from the piping diameter.

ESTABLISHING DUTY REQUIREMENTS

Before a pump is selected and installed, one must know the



duties the pump will have to perform, *viz.*, quantity to be discharged and total head to be overcome. The total head comprises a part called frictional head. This frictional head is mainly due to the pipes and fittings which in turn depend on the velocity of flow and the diameter and length of the pipes. Thus a critical study for selecting the most suitable piping, which is economic and which allows the pump to work at good efficiency, is necessary. The main factors for a sound and economical pumping plant are :—

(1) Cost of piping and valves
(2) Cost of pump, motor and starter
(3) Electrical running costs and hours of pumping.

Let us consider some problems to establish the duty requirements.

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Problem 1

Amount of water to be pumped per day = 1350 m³
Number of hours of pumping/day = 6
Thus the expected pumping per hour would be 225 m³.

Let there be a static head of 28 m with 60 m of straight piping with 6 elbows, 2 non-return valves and 1 main valve.

The choice of piping diameter may lie between 15, 20 and 25 cm.

With 15 cm pipe diameter and 225 m³ quantity, the losses in fitting as found out from the Nomogram–1 facing page 59 shall be approximately as given below :—

6 Elbows = 6 × 190 = 1140 mm
2 Gate Valves = 2 × 500 = 1000 mm
1 Sluice Valve = 1275 = 1275 mm
Now losses in 60 m piping = 60 × 120 = 7200 mm
Total friction losses = 10·6 m

Suitably considering future wear, etc., the friction loss may be taken as 13·5 m.

∴ Total frictional head for 15 cm pipe equals 13·5 m
Similarly ,, ,, ,, ,, 20 ,, ,, ,, 4·0 m
,, ,, ,, ,, ,, 25 ,, ,, ,, 1·6 m

The total dynamic head in each case would be :—

for 15 cm pipe — (28 + 13·5) = 41·5 m
for 20 cm pipe — (28 + 4) = 32·0 m
for 25 cm pipe — (28 + 1·6) = 29·6 m

For 15 cm piping, quantity to be pumped is 225 m³/h and head against which the pump has to work is 41·5 m, the horse power required would be 46 and efficiency would be 74%. With 90% motor efficiency, the power input would be 38 kW.

6 hours/day means total power consumption would be 218 kWh.

Approximate capital cost of 15 cm high head pump with 50 h. p. motor is Rs. 16500.

For 20 cm piping, 225 m³/h quantity and 32 m head, the horse power required would be 32 with efficiency about 82%. With 90% motor efficiency, power input will be 26·5 kW and total power consumed per day would be 159 kWh. Approximate cost for 40 h. p. pump-motor unit is Rs. 15000.

For 25 cm piping, 223 m³/h quantity and 29·6 m head, the horse power required would be 29·6 with 82% efficiency. With 90% motor efficiency, the total power required would be 24·5 kW or the power consumption per day would be 147 kWh.

Now approximate cost of pump with 30 h. p. motor is Rs. 12500.

The total cost of full unit, *i. e.*, the pump, motor, pipings and fittings may be around the figures as follows :—

For 15 cm piping	Rs. 22800
,, 20 cm ,,	Rs. 22500
,, 25 cm ,,	Rs. 23500

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Thus in the initial investments, 20 cm piping would be cheapest.

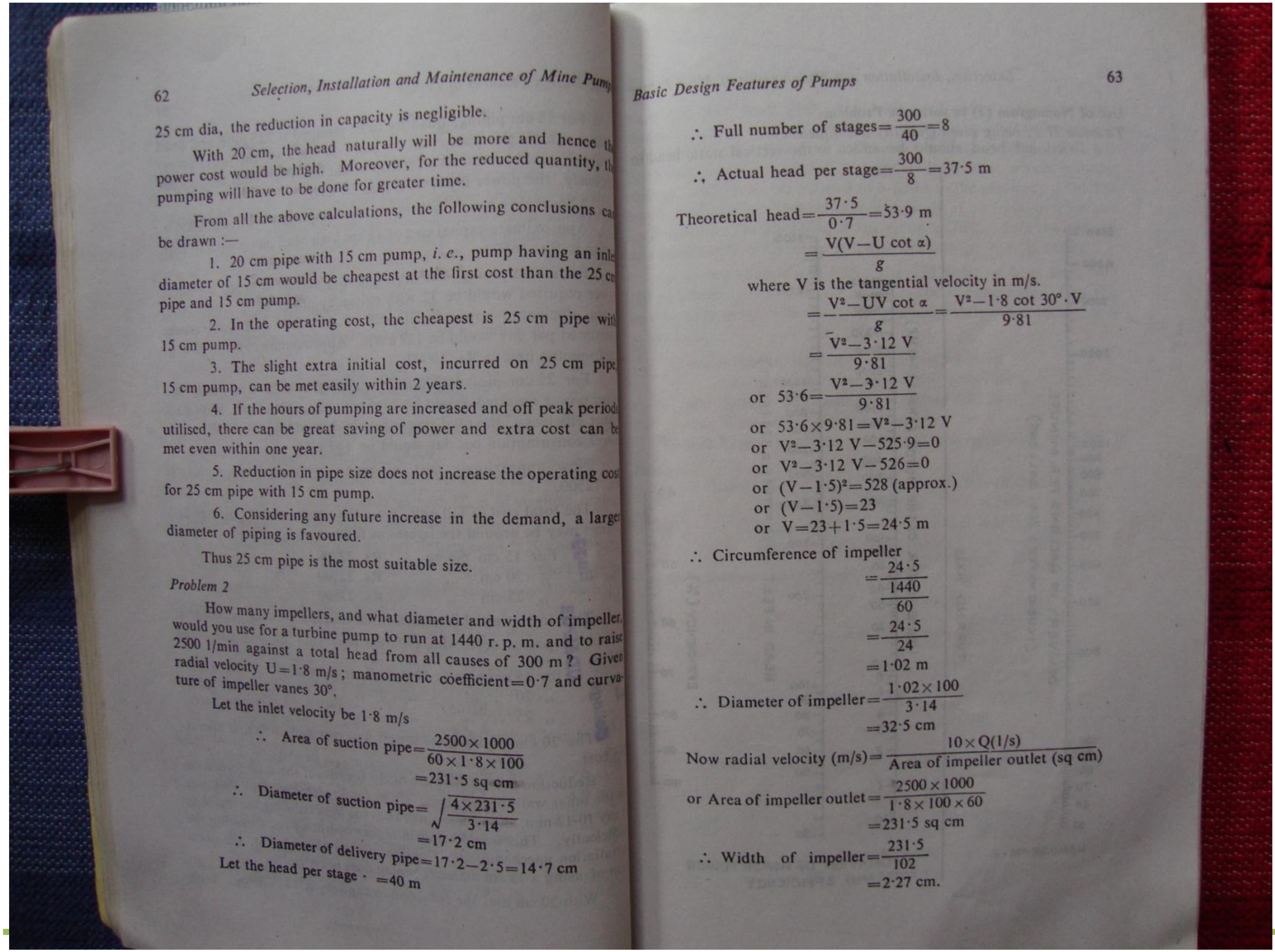
Now power costs with different pipe sites for one year would be :—

for 15 cm pipe @ 10 paise/unit (approx.)	= Rs. 8300
,, 20 ,, ,, ,, ,,	= Rs. 5800
,, 25 ,, ,, ,, ,,	= Rs. 5400

The 20 cm piping gives lowest first cost and attractive operating cost.

Reduction in pipe sizes are likely because of the scale formation on the inner walls of the pipes. If the total reduction in the diameter is say 10-12 mm, the system curve rises too high reducing the quantity sufficiently. This would result in higher operating cost, making the installation uneconomical. Considering the above factor, the question of using a 15 cm diameter piping does not arise.

With 20 cm dia, the reduction in capacity is 13·5 m³/h. With



25 cm dia, the reduction in capacity is negligible.

With 20 cm, the head naturally will be more and hence th power cost would be high. Moreover, for the reduced quantity, th pumping will have to be done for greater time.

From all the above calculations, the following conclusions ca be drawn :—

1. 20 cm pipe with 15 cm pump, *i. e.*, pump having an inle diameter of 15 cm would be cheapest at the first cost than the 25 c pipe and 15 cm pump.

2. In the operating cost, the cheapest is 25 cm pipe wit 15 cm pump.

3. The slight extra initial cost, incurred on 25 cm pipe 15 cm pump, can be met easily within 2 years.

4. If the hours of pumping are increased and off peak period utilised, there can be great saving of power and extra cost can b met even within one year.

5. Reduction in pipe size does not increase the operating cos for 25 cm pipe with 15 cm pump.

6. Considering any future increase in the demand, a larger diameter of piping is favoured.

Thus 25 cm pipe is the most suitable size.

Problem 2

How many impellers, and what diameter and width of impeller, would you use for a turbine pump to run at 1440 r. p. m. and to raise 2500 l/min against a total head from all causes of 300 m? Given radial velocity $U=1{\cdot}8$ m/s; manometric coefficient $=0{\cdot}7$ and curva- ture of impeller vanes 30°.

Let the inlet velocity be 1·8 m/s

$$\therefore \text{ Area of suction pipe}=\frac{2500\times1000}{60\times1{\cdot}8\times100}$$

$$=231{\cdot}5 \text{ sq cm}$$

$$\therefore \text{ Diameter of suction pipe}=\sqrt{\frac{4\times231{\cdot}5}{3{\cdot}14}}$$

$$=17{\cdot}2 \text{ cm}$$

$$\therefore \text{ Diameter of delivery pipe}=17{\cdot}2-2{\cdot}5=14{\cdot}7 \text{ cm}$$

Let the head per stage $=40$ m

$$\therefore \text{ Full number of stages}=\frac{300}{40}=8$$

$$\therefore \text{ Actual head per stage}=\frac{300}{8}=37{\cdot}5 \text{ m}$$

$$\text{Theoretical head}=\frac{37{\cdot}5}{0{\cdot}7}=53{\cdot}9 \text{ m}$$

$$=\frac{V(V-U\cot\alpha)}{g}$$

where V is the tangential velocity in m/s.

$$=\frac{V^2-UV\cot\alpha}{g}=\frac{V^2-1{\cdot}8\cot30^\circ\cdot V}{9{\cdot}81}$$

$$=\frac{V^2-3{\cdot}12\,V}{9{\cdot}81}$$

$$\text{or }\ 53{\cdot}6=\frac{V^2-3{\cdot}12\,V}{9{\cdot}81}$$

$$\text{or }\ 53{\cdot}6\times9{\cdot}81=V^2-3{\cdot}12\,V$$

$$\text{or }\ V^2-3{\cdot}12\,V-525{\cdot}9=0$$

$$\text{or }\ V^2-3{\cdot}12\,V-526=0$$

$$\text{or }\ (V-1{\cdot}5)^2=528 \text{ (approx.)}$$

$$\text{or }\ (V-1{\cdot}5)=23$$

$$\text{or }\ V=23+1{\cdot}5=24{\cdot}5 \text{ m}$$

$$\therefore \text{ Circumference of impeller}$$

$$=\frac{24{\cdot}5}{\frac{1440}{60}}$$

$$=\frac{24{\cdot}5}{24}$$

$$=1{\cdot}02 \text{ m}$$

$$\therefore \text{ Diameter of impeller}=\frac{1{\cdot}02\times100}{3{\cdot}14}$$

$$=32{\cdot}5 \text{ cm}$$

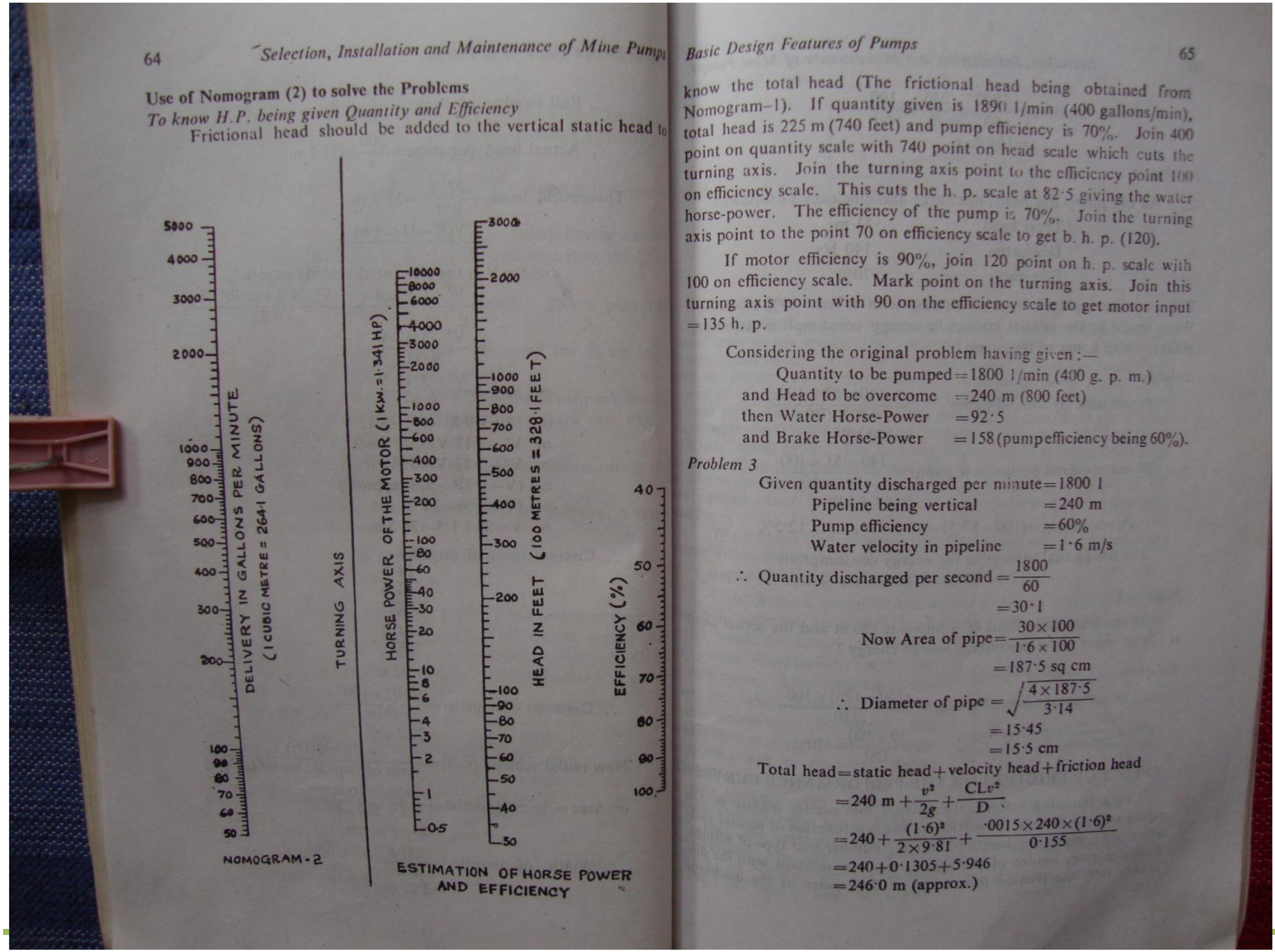
$$\text{Now radial velocity (m/s)}=\frac{10\times Q(l/s)}{\text{Area of impeller outlet (sq cm)}}$$

$$\text{or Area of impeller outlet}=\frac{2500\times1000}{1{\cdot}8\times100\times60}$$

$$=231{\cdot}5 \text{ sq cm}$$

$$\therefore \text{ Width of impeller}=\frac{231{\cdot}5}{102}$$

$$=2{\cdot}27 \text{ cm.}$$



64 *Selection, Installation and Maintenance of Mine Pumps*

Use of Nomogram (2) to solve the Problems

To know H.P. being given Quantity and Efficiency

Frictional head should be added to the vertical static head to

5000
4000
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
DELIVERY IN GALLONS PER MINUTE
(1 CUBIC METRE = 264·1 GALLONS)
TURNING AXIS
10000
8000
6000
4000
3000
2000
1000
800
600
400
300
200
100
80
60
40
30
20
10
8
6
4
3
2
1
0·5
HORSE POWER OF THE MOTOR (1 KW.=1·341 H.P.)
3000
2000
1000
900
800
700
600
500
400
300
200
100
90
80
70
60
50
40
30
HEAD IN FEET (100 METRES = 328·1 FEET)
40
50
60
70
80
90
100
EFFICIENCY (%)

NOMOGRAM-2

ESTIMATION OF HORSE POWER
AND EFFICIENCY

Basic Design Features of Pumps 65

know the total head (The frictional head being obtained from Nomogram–1). If quantity given is 1890 l/min (400 gallons/min), total head is 225 m (740 feet) and pump efficiency is 70%. Join 400 point on quantity scale with 740 point on head scale which cuts the turning axis. Join the turning axis point to the efficiency point 100 on efficiency scale. This cuts the h. p. scale at 82·5 giving the water horse-power. The efficiency of the pump is 70%. Join the turning axis point to the point 70 on efficiency scale to get b. h. p. (120).

If motor efficiency is 90%, join 120 point on h. p. scale with 100 on efficiency scale. Mark point on the turning axis. Join this turning axis point with 90 on the efficiency scale to get motor input =135 h. p.

Considering the original problem having given :—

Quantity to be pumped = 1800 l/min (400 g. p. m.)
and Head to be overcome = 240 m (800 feet)
then Water Horse-Power = 92·5
and Brake Horse-Power = 158 (pump efficiency being 60%).

Problem 3

Given quantity discharged per minute = 1800 l
Pipeline being vertical = 240 m
Pump efficiency = 60%
Water velocity in pipeline = 1·6 m/s

$$\therefore \text{ Quantity discharged per second} = \frac{1800}{60}$$

$$= 30\cdot 1$$

$$\text{Now Area of pipe} = \frac{30 \times 100}{1\cdot 6 \times 100}$$

$$= 187\cdot 5 \text{ sq cm}$$

$$\therefore \text{ Diameter of pipe} = \sqrt{\frac{4 \times 187\cdot 5}{3\cdot 14}}$$

$$= 15\cdot 45$$

$$= 15\cdot 5 \text{ cm}$$

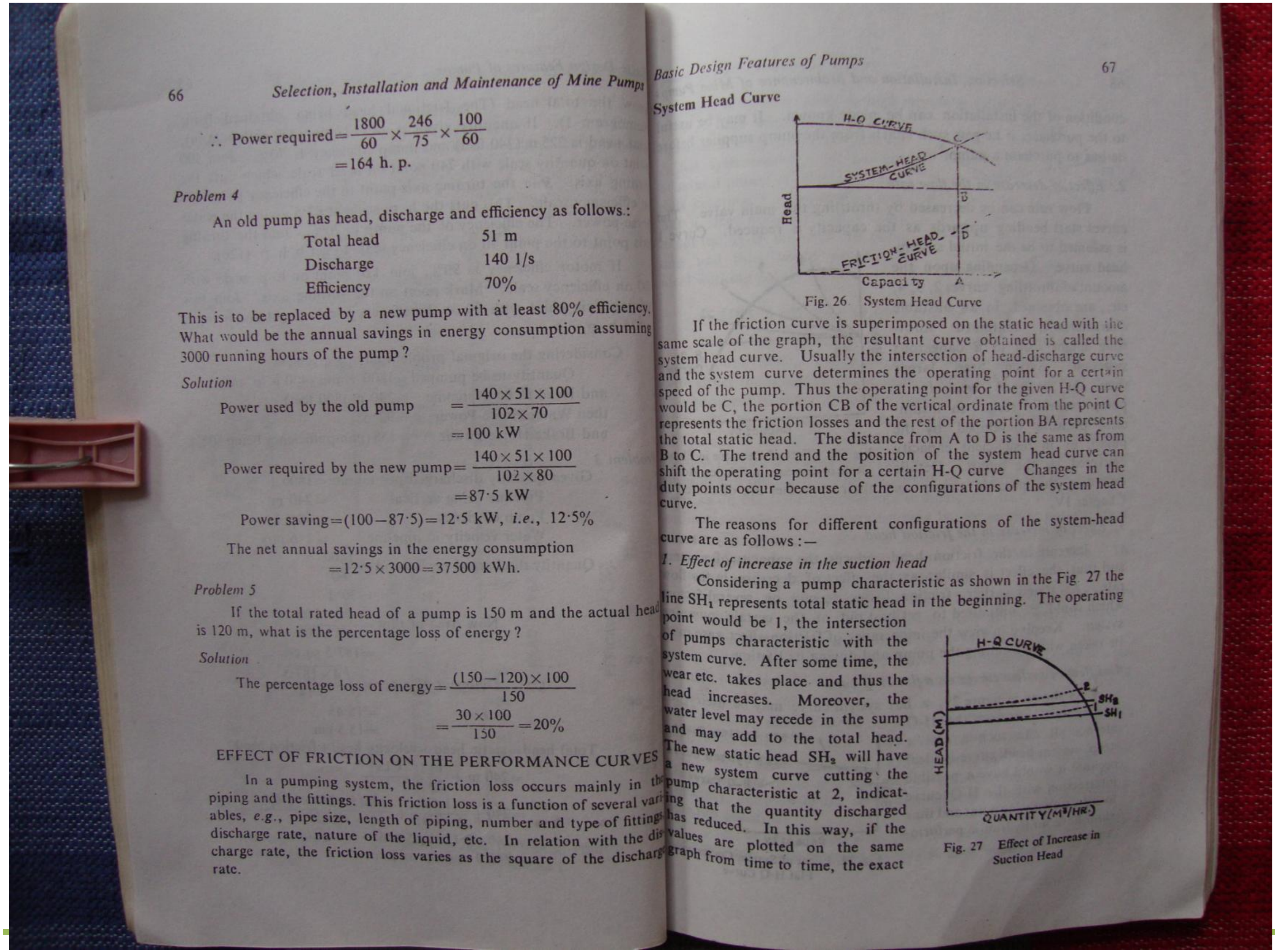
Total head = static head + velocity head + friction head

$$= 240 \text{ m} + \frac{v^2}{2g} + \frac{CLv^2}{D}$$

$$= 240 + \frac{(1\cdot 6)^2}{2 \times 9\cdot 81} + \frac{\cdot 0015 \times 240 \times (1\cdot 6)^2}{0\cdot 155}$$

$$= 240 + 0\cdot 1305 + 5\cdot 946$$

$$= 246\cdot 0 \text{ m (approx.)}$$



$$\therefore \text{ Power required} = \frac{1800}{60} \times \frac{246}{75} \times \frac{100}{60}$$

$$= 164 \text{ h. p.}$$

Problem 4

An old pump has head, discharge and efficiency as follows:

Total head	51 m
Discharge	140 l/s
Efficiency	70%

This is to be replaced by a new pump with at least 80% efficiency. What would be the annual savings in energy consumption assuming 3000 running hours of the pump ?

Solution

$$\text{Power used by the old pump} = \frac{140 \times 51 \times 100}{102 \times 70}$$

$$= 100 \text{ kW}$$

$$\text{Power required by the new pump} = \frac{140 \times 51 \times 100}{102 \times 80}$$

$$= 87{\cdot}5 \text{ kW}$$

Power saving $= (100 - 87{\cdot}5) = 12{\cdot}5$ kW, *i.e.*, $12{\cdot}5\%$

The net annual savings in the energy consumption $= 12{\cdot}5 \times 3000 = 37500$ kWh.

Problem 5

If the total rated head of a pump is 150 m and the actual head is 120 m, what is the percentage loss of energy ?

Solution

$$\text{The percentage loss of energy} = \frac{(150-120) \times 100}{150}$$

$$= \frac{30 \times 100}{150} = 20\%$$

EFFECT OF FRICTION ON THE PERFORMANCE CURVES

In a pumping system, the friction loss occurs mainly in th piping and the fittings. This friction loss is a function of several variables, *e.g.*, pipe size, length of piping, number and type of fittings discharge rate, nature of the liquid, etc. In relation with the discharg rate, the friction loss varies as the square of the discharg rate.

System Head Curve

Fig. 26 System Head Curve

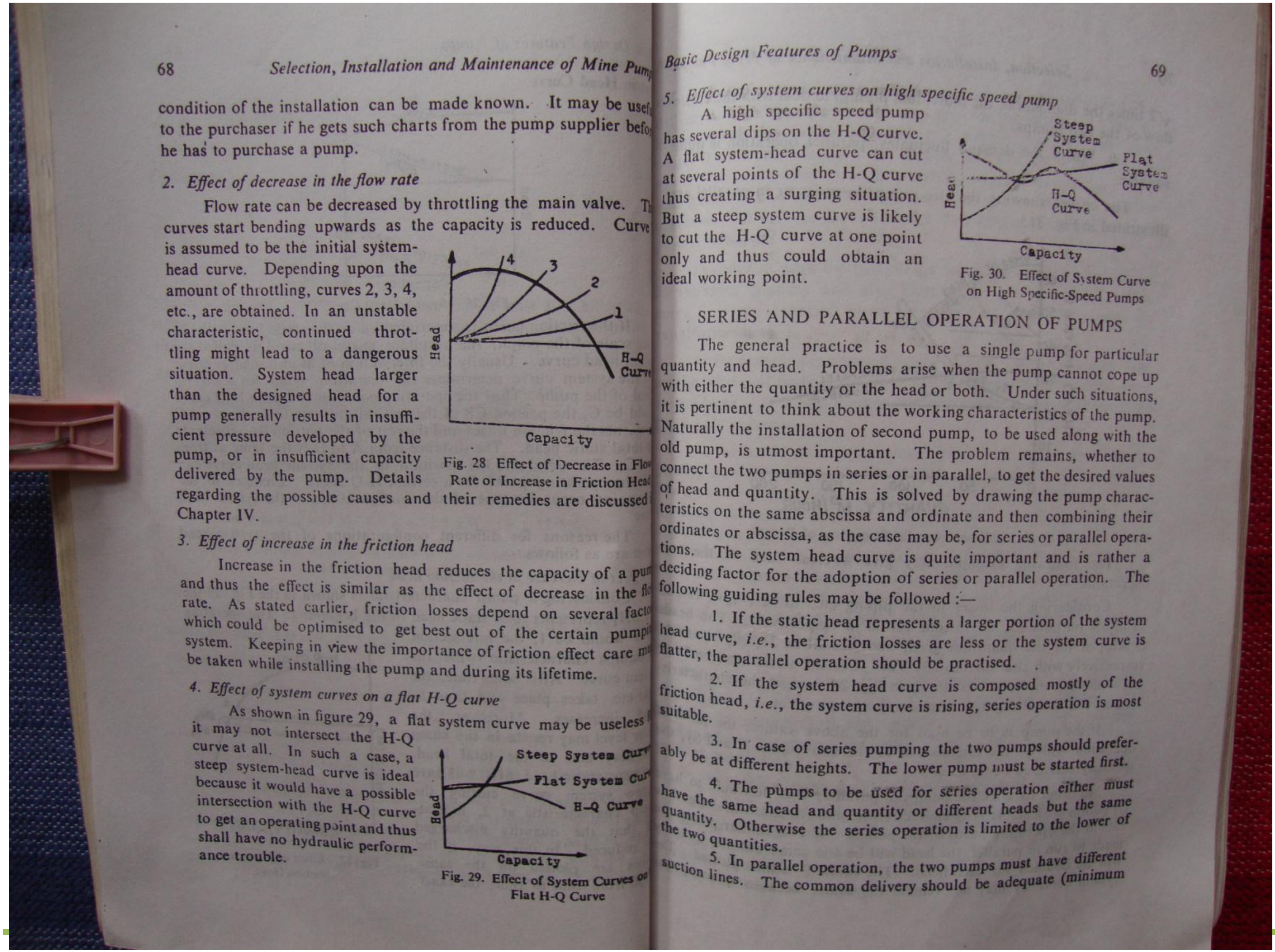
If the friction curve is superimposed on the static head with the same scale of the graph, the resultant curve obtained is called the system head curve. Usually the intersection of head-discharge curve and the system curve determines the operating point for a certain speed of the pump. Thus the operating point for the given H-Q curve would be C, the portion CB of the vertical ordinate from the point C represents the friction losses and the rest of the portion BA represents the total static head. The distance from A to D is the same as from B to C. The trend and the position of the system head curve can shift the operating point for a certain H-Q curve Changes in the duty points occur because of the configurations of the system head curve.

The reasons for different configurations of the system-head curve are as follows :—

1. Effect of increase in the suction head

Considering a pump characteristic as shown in the Fig. 27 the line SH_1 represents total static head in the beginning. The operating point would be 1, the intersection of pumps characteristic with the system curve. After some time, the wear etc. takes place and thus the head increases. Moreover, the water level may recede in the sump and may add to the total head. The new static head SH_2 will have a new system curve cutting the pump characteristic at 2, indicating that the quantity discharged has reduced. In this way, if the values are plotted on the same graph from time to time, the exact

Fig. 27 Effect of Increase in Suction Head



condition of the installation can be made known. It may be usef to the purchaser if he gets such charts from the pump supplier befo he has to purchase a pump.

2. *Effect of decrease in the flow rate*

Flow rate can be decreased by throttling the main valve. T curves start bending upwards as the capacity is reduced. Curve is assumed to be the initial system-head curve. Depending upon the amount of throttling, curves 2, 3, 4, etc., are obtained. In an unstable characteristic, continued throttling might lead to a dangerous situation. System head larger than the designed head for a pump generally results in insufficient pressure developed by the pump, or in insufficient capacity delivered by the pump. Details regarding the possible causes and their remedies are discussed Chapter IV.

Fig. 28 Effect of Decrease in Flo Rate or Increase in Friction Hea

3. *Effect of increase in the friction head*

Increase in the friction head reduces the capacity of a pu and thus the effect is similar as the effect of decrease in the fl rate. As stated earlier, friction losses depend on several facto which could be optimised to get best out of the certain pumpi system. Keeping in view the importance of friction effect care m be taken while installing the pump and during its lifetime.

4. *Effect of system curves on a flat H-Q curve*

As shown in figure 29, a flat system curve may be useless it may not intersect the H-Q curve at all. In such a case, a steep system-head curve is ideal because it would have a possible intersection with the H-Q curve to get an operating point and thus shall have no hydraulic performance trouble.

Fig. 29. Effect of System Curves o Flat H-Q Curve

5. *Effect of system curves on high specific speed pump*

A high specific speed pump has several dips on the H-Q curve. A flat system-head curve can cut at several points of the H-Q curve thus creating a surging situation. But a steep system curve is likely to cut the H-Q curve at one point only and thus could obtain an ideal working point.

Fig. 30. Effect of System Curve on High Specific-Speed Pumps

SERIES AND PARALLEL OPERATION OF PUMPS

The general practice is to use a single pump for particular quantity and head. Problems arise when the pump cannot cope up with either the quantity or the head or both. Under such situations, it is pertinent to think about the working characteristics of the pump. Naturally the installation of second pump, to be used along with the old pump, is utmost important. The problem remains, whether to connect the two pumps in series or in parallel, to get the desired values of head and quantity. This is solved by drawing the pump characteristics on the same abscissa and ordinate and then combining their ordinates or abscissa, as the case may be, for series or parallel operations. The system head curve is quite important and is rather a deciding factor for the adoption of series or parallel operation. The following guiding rules may be followed :—

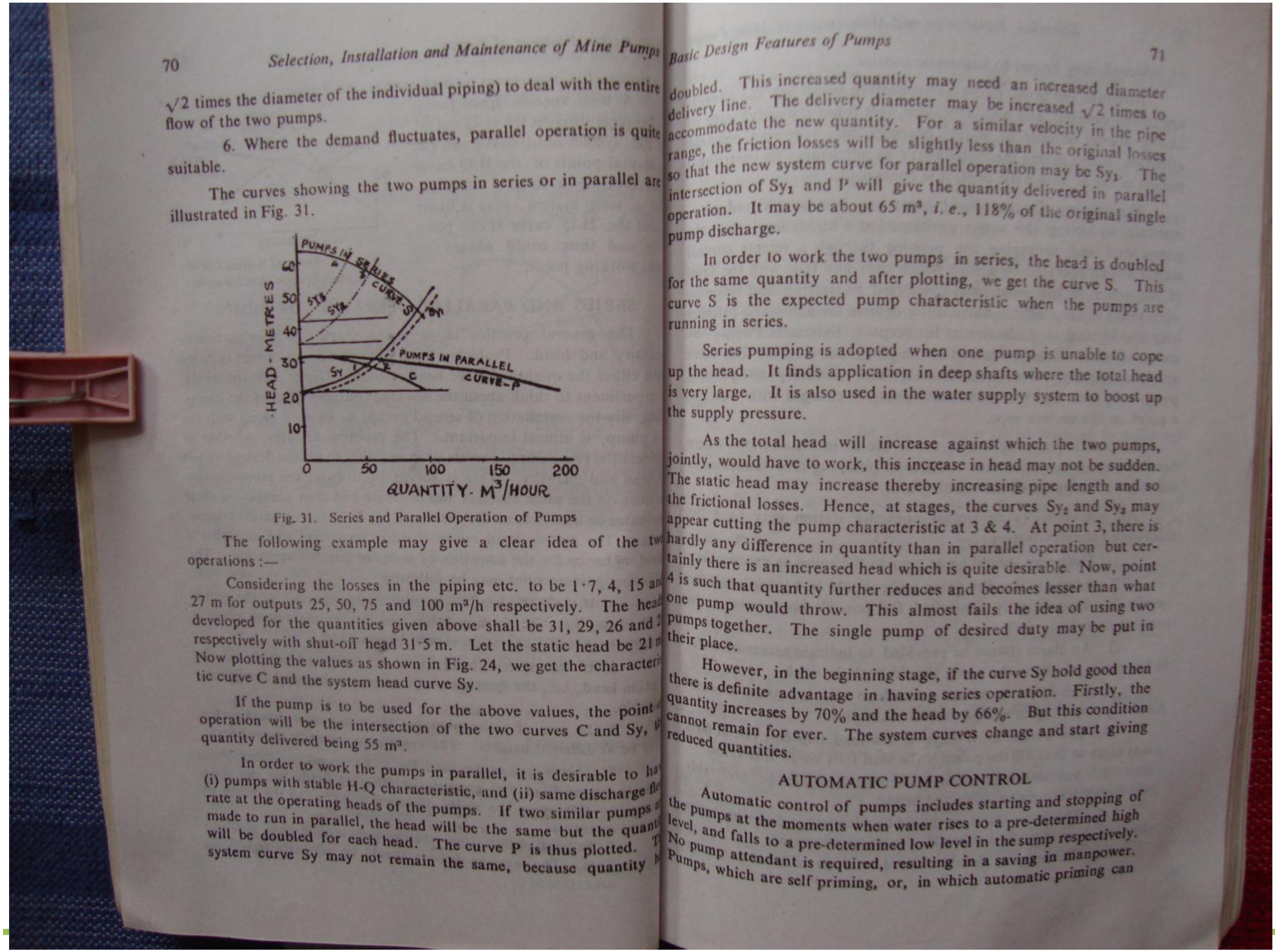
1. If the static head represents a larger portion of the system head curve, *i.e.*, the friction losses are less or the system curve is flatter, the parallel operation should be practised.

2. If the system head curve is composed mostly of the friction head, *i.e.*, the system curve is rising, series operation is most suitable.

3. In case of series pumping the two pumps should preferably be at different heights. The lower pump must be started first.

4. The pumps to be used for series operation either must have the same head and quantity or different heads but the same quantity. Otherwise the series operation is limited to the lower of the two quantities.

5. In parallel operation, the two pumps must have different suction lines. The common delivery should be adequate (minimum



$\sqrt{2}$ times the diameter of the individual piping) to deal with the entire flow of the two pumps.

6. Where the demand fluctuates, parallel operation is quite suitable.

The curves showing the two pumps in series or in parallel are illustrated in Fig. 31.

PUMPS IN SERIES CURVE-S
4
3
SY3
SY2
SY1
PUMPS IN PARALLEL CURVE-P
SY
1
2
C
HEAD - METRES
60
50
40
30
20
10
0
50
100
150
200
QUANTITY- M^3/HOUR

Fig. 31. Series and Parallel Operation of Pumps

The following example may give a clear idea of the tw operations :—

Considering the losses in the piping etc. to be 1·7, 4, 15 an 27 m for outputs 25, 50, 75 and 100 m³/h respectively. The head developed for the quantities given above shall be 31, 29, 26 and 2 respectively with shut-off head 31·5 m. Let the static head be 21 m Now plotting the values as shown in Fig. 24, we get the characteri tic curve C and the system head curve Sy.

If the pump is to be used for the above values, the point operation will be the intersection of the two curves C and Sy, t quantity delivered being 55 m³.

In order to work the pumps in parallel, it is desirable to ha (i) pumps with stable H-Q characteristic, and (ii) same discharge flo rate at the operating heads of the pumps. If two similar pumps a made to run in parallel, the head will be the same but the quanti will be doubled for each head. The curve P is thus plotted. T system curve Sy may not remain the same, because quantity h

doubled. This increased quantity may need an increased diameter delivery line. The delivery diameter may be increased $\sqrt{2}$ times to accommodate the new quantity. For a similar velocity in the pipe range, the friction losses will be slightly less than the original losses so that the new system curve for parallel operation may be Sy_1. The intersection of Sy_1 and P will give the quantity delivered in parallel operation. It may be about 65 m³, *i. e.*, 118% of the original single pump discharge.

In order to work the two pumps in series, the head is doubled for the same quantity and after plotting, we get the curve S. This curve S is the expected pump characteristic when the pumps are running in series.

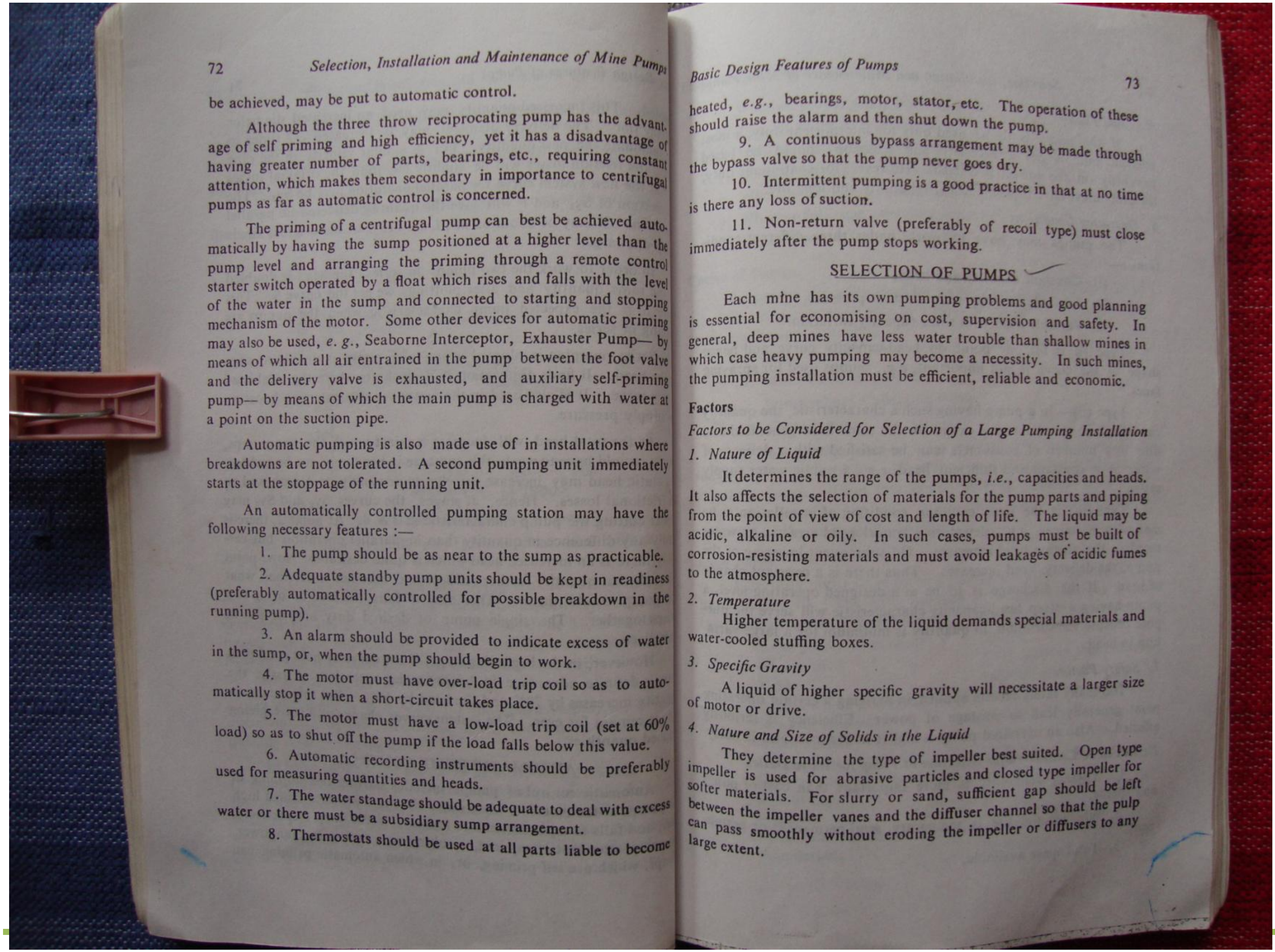
Series pumping is adopted when one pump is unable to cope up the head. It finds application in deep shafts where the total head is very large. It is also used in the water supply system to boost up the supply pressure.

As the total head will increase against which the two pumps, jointly, would have to work, this increase in head may not be sudden. The static head may increase thereby increasing pipe length and so the frictional losses. Hence, at stages, the curves Sy_2 and Sy_3 may appear cutting the pump characteristic at 3 & 4. At point 3, there is hardly any difference in quantity than in parallel operation but certainly there is an increased head which is quite desirable. Now, point 4 is such that quantity further reduces and becomes lesser than what one pump would throw. This almost fails the idea of using two pumps together. The single pump of desired duty may be put in their place.

However, in the beginning stage, if the curve Sy hold good then there is definite advantage in having series operation. Firstly, the quantity increases by 70% and the head by 66%. But this condition cannot remain for ever. The system curves change and start giving reduced quantities.

AUTOMATIC PUMP CONTROL

Automatic control of pumps includes starting and stopping of the pumps at the moments when water rises to a pre-determined high level, and falls to a pre-determined low level in the sump respectively. No pump attendant is required, resulting in a saving in manpower. Pumps, which are self priming, or, in which automatic priming can



be achieved, may be put to automatic control.

Although the three throw reciprocating pump has the advantage of self priming and high efficiency, yet it has a disadvantage of having greater number of parts, bearings, etc., requiring constant attention, which makes them secondary in importance to centrifugal pumps as far as automatic control is concerned.

The priming of a centrifugal pump can best be achieved automatically by having the sump positioned at a higher level than the pump level and arranging the priming through a remote control starter switch operated by a float which rises and falls with the level of the water in the sump and connected to starting and stopping mechanism of the motor. Some other devices for automatic priming may also be used, *e. g.*, Seaborne Interceptor, Exhauster Pump— by means of which all air entrained in the pump between the foot valve and the delivery valve is exhausted, and auxiliary self-priming pump— by means of which the main pump is charged with water at a point on the suction pipe.

Automatic pumping is also made use of in installations where breakdowns are not tolerated. A second pumping unit immediately starts at the stoppage of the running unit.

An automatically controlled pumping station may have the following necessary features :—

1. The pump should be as near to the sump as practicable.
2. Adequate standby pump units should be kept in readiness (preferably automatically controlled for possible breakdown in the running pump).
3. An alarm should be provided to indicate excess of water in the sump, or, when the pump should begin to work.
4. The motor must have over-load trip coil so as to automatically stop it when a short-circuit takes place.
5. The motor must have a low-load trip coil (set at 60% load) so as to shut off the pump if the load falls below this value.
6. Automatic recording instruments should be preferably used for measuring quantities and heads.
7. The water standage should be adequate to deal with excess water or there must be a subsidiary sump arrangement.
8. Thermostats should be used at all parts liable to become heated, *e.g.*, bearings, motor, stator, etc. The operation of these should raise the alarm and then shut down the pump.
9. A continuous bypass arrangement may be made through the bypass valve so that the pump never goes dry.
10. Intermittent pumping is a good practice in that at no time is there any loss of suction.
11. Non-return valve (preferably of recoil type) must close immediately after the pump stops working.

SELECTION OF PUMPS

Each mine has its own pumping problems and good planning is essential for economising on cost, supervision and safety. In general, deep mines have less water trouble than shallow mines in which case heavy pumping may become a necessity. In such mines, the pumping installation must be efficient, reliable and economic.

Factors

Factors to be Considered for Selection of a Large Pumping Installation

1. Nature of Liquid

It determines the range of the pumps, *i.e.*, capacities and heads. It also affects the selection of materials for the pump parts and piping from the point of view of cost and length of life. The liquid may be acidic, alkaline or oily. In such cases, pumps must be built of corrosion-resisting materials and must avoid leakages of acidic fumes to the atmosphere.

2. Temperature

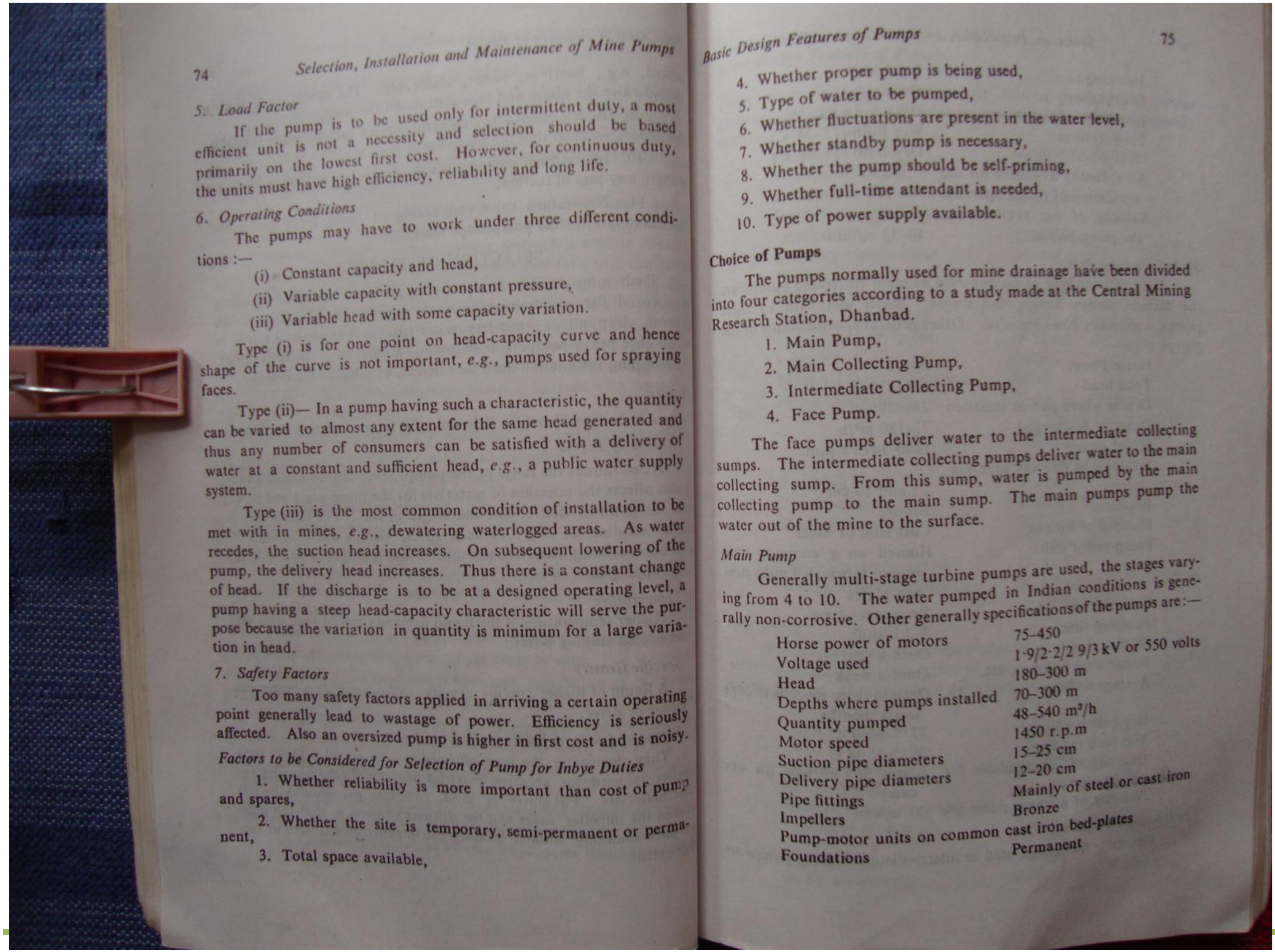
Higher temperature of the liquid demands special materials and water-cooled stuffing boxes.

3. Specific Gravity

A liquid of higher specific gravity will necessitate a larger size of motor or drive.

4. Nature and Size of Solids in the Liquid

They determine the type of impeller best suited. Open type impeller is used for abrasive particles and closed type impeller for softer materials. For slurry or sand, sufficient gap should be left between the impeller vanes and the diffuser channel so that the pulp can pass smoothly without eroding the impeller or diffusers to any large extent.



5. Load Factor

If the pump is to be used only for intermittent duty, a most efficient unit is not a necessity and selection should be based primarily on the lowest first cost. However, for continuous duty, the units must have high efficiency, reliability and long life.

6. Operating Conditions

The pumps may have to work under three different conditions :—

(i) Constant capacity and head,
(ii) Variable capacity with constant pressure,
(iii) Variable head with some capacity variation.

Type (i) is for one point on head-capacity curve and hence shape of the curve is not important, *e.g.*, pumps used for spraying faces.

Type (ii)— In a pump having such a characteristic, the quantity can be varied to almost any extent for the same head generated and thus any number of consumers can be satisfied with a delivery of water at a constant and sufficient head, *e.g.*, a public water supply system.

Type (iii) is the most common condition of installation to be met with in mines, *e.g.*, dewatering waterlogged areas. As water recedes, the suction head increases. On subsequent lowering of the pump, the delivery head increases. Thus there is a constant change of head. If the discharge is to be at a designed operating level, a pump having a steep head-capacity characteristic will serve the purpose because the variation in quantity is minimum for a large variation in head.

7. Safety Factors

Too many safety factors applied in arriving a certain operating point generally lead to wastage of power. Efficiency is seriously affected. Also an oversized pump is higher in first cost and is noisy.

Factors to be Considered for Selection of Pump for Inbye Duties

1. Whether reliability is more important than cost of pump and spares,
2. Whether the site is temporary, semi-permanent or permanent,
3. Total space available,

4. Whether proper pump is being used,
5. Type of water to be pumped,
6. Whether fluctuations are present in the water level,
7. Whether standby pump is necessary,
8. Whether the pump should be self-priming,
9. Whether full-time attendant is needed,
10. Type of power supply available.

Choice of Pumps

The pumps normally used for mine drainage have been divided into four categories according to a study made at the Central Mining Research Station, Dhanbad.

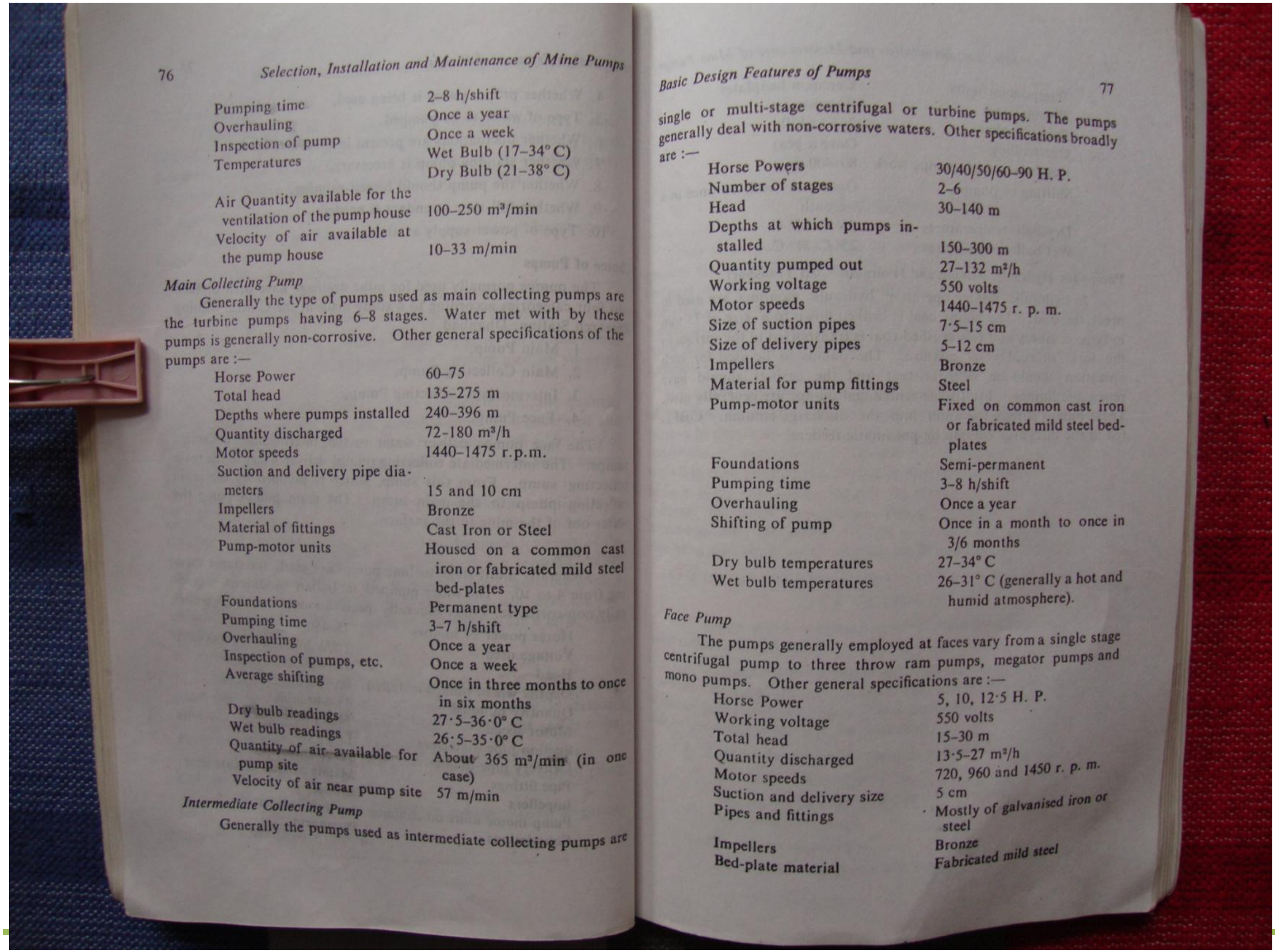
1. Main Pump,
2. Main Collecting Pump,
3. Intermediate Collecting Pump,
4. Face Pump.

The face pumps deliver water to the intermediate collecting sumps. The intermediate collecting pumps deliver water to the main collecting sump. From this sump, water is pumped by the main collecting pump to the main sump. The main pumps pump the water out of the mine to the surface.

Main Pump

Generally multi-stage turbine pumps are used, the stages varying from 4 to 10. The water pumped in Indian conditions is generally non-corrosive. Other generally specifications of the pumps are:—

Horse power of motors	75–450
Voltage used	1·9/2·2/2 9/3 kV or 550 volts
Head	180–300 m
Depths where pumps installed	70–300 m
Quantity pumped	48–540 m^3/h
Motor speed	1450 r.p.m
Suction pipe diameters	15–25 cm
Delivery pipe diameters	12–20 cm
Pipe fittings	Mainly of steel or cast iron
Impellers	Bronze
Pump-motor units on common cast iron bed-plates	
Foundations	Permanent



Pumping time	2–8 h/shift
Overhauling	Once a year
Inspection of pump	Once a week
Temperatures	Wet Bulb (17–34° C) Dry Bulb (21–38° C)
Air Quantity available for the ventilation of the pump house	100–250 m³/min
Velocity of air available at the pump house	10–33 m/min

Main Collecting Pump

Generally the type of pumps used as main collecting pumps are the turbine pumps having 6–8 stages. Water met with by these pumps is generally non-corrosive. Other general specifications of the pumps are :—

Horse Power	60–75
Total head	135–275 m
Depths where pumps installed	240–396 m
Quantity discharged	72–180 m³/h
Motor speeds	1440–1475 r.p.m.
Suction and delivery pipe diameters	15 and 10 cm
Impellers	Bronze
Material of fittings	Cast Iron or Steel
Pump-motor units	Housed on a common cast iron or fabricated mild steel bed-plates
Foundations	Permanent type
Pumping time	3–7 h/shift
Overhauling	Once a year
Inspection of pumps, etc.	Once a week
Average shifting	Once in three months to once in six months
Dry bulb readings	27·5–36·0° C
Wet bulb readings	26·5–35·0° C
Quantity of air available for pump site	About 365 m³/min (in one case)
Velocity of air near pump site	57 m/min

Intermediate Collecting Pump

Generally the pumps used as intermediate collecting pumps are

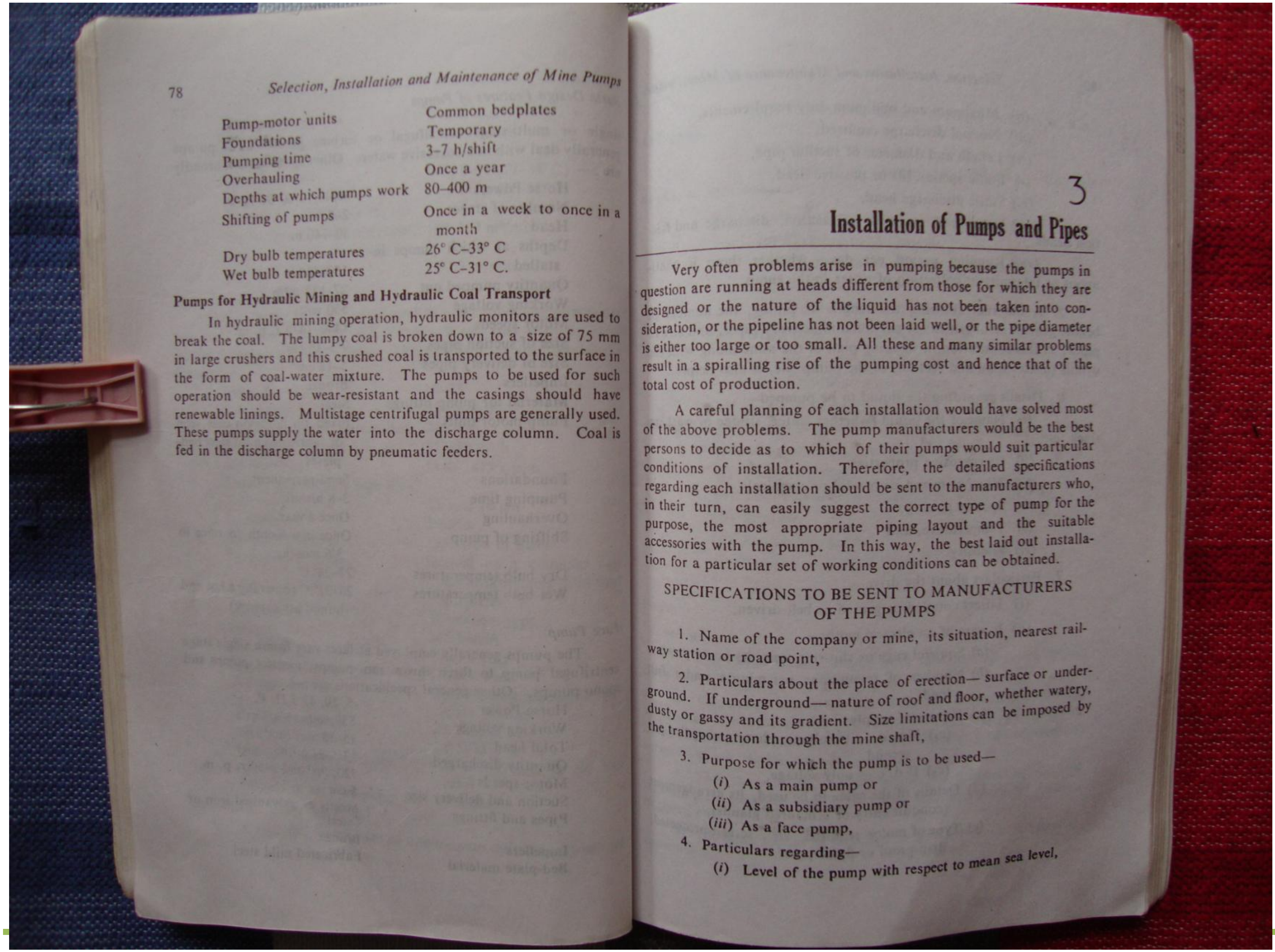
single or multi-stage centrifugal or turbine pumps. The pumps generally deal with non-corrosive waters. Other specifications broadly are :—

Horse Powers	30/40/50/60–90 H. P.
Number of stages	2–6
Head	30–140 m
Depths at which pumps installed	150–300 m
Quantity pumped out	27–132 m³/h
Working voltage	550 volts
Motor speeds	1440–1475 r. p. m.
Size of suction pipes	7·5–15 cm
Size of delivery pipes	5–12 cm
Impellers	Bronze
Material for pump fittings	Steel
Pump-motor units	Fixed on common cast iron or fabricated mild steel bed-plates
Foundations	Semi-permanent
Pumping time	3–8 h/shift
Overhauling	Once a year
Shifting of pump	Once in a month to once in 3/6 months
Dry bulb temperatures	27–34° C
Wet bulb temperatures	26–31° C (generally a hot and humid atmosphere).

Face Pump

The pumps generally employed at faces vary from a single stage centrifugal pump to three throw ram pumps, megator pumps and mono pumps. Other general specifications are :—

Horse Power	5, 10, 12·5 H. P.
Working voltage	550 volts
Total head	15–30 m
Quantity discharged	13·5–27 m³/h
Motor speeds	720, 960 and 1450 r. p. m.
Suction and delivery size	5 cm
Pipes and fittings	Mostly of galvanised iron or steel
Impellers	Bronze
Bed-plate material	Fabricated mild steel



Pump-motor units	Common bedplates
Foundations	Temporary
Pumping time	3–7 h/shift
Overhauling	Once a year
Depths at which pumps work	80–400 m
Shifting of pumps	Once in a week to once in a month
Dry bulb temperatures	26° C–33° C
Wet bulb temperatures	25° C–31° C.

Pumps for Hydraulic Mining and Hydraulic Coal Transport

In hydraulic mining operation, hydraulic monitors are used to break the coal. The lumpy coal is broken down to a size of 75 mm in large crushers and this crushed coal is transported to the surface in the form of coal-water mixture. The pumps to be used for such operation should be wear-resistant and the casings should have renewable linings. Multistage centrifugal pumps are generally used. These pumps supply the water into the discharge column. Coal is fed in the discharge column by pneumatic feeders.

3

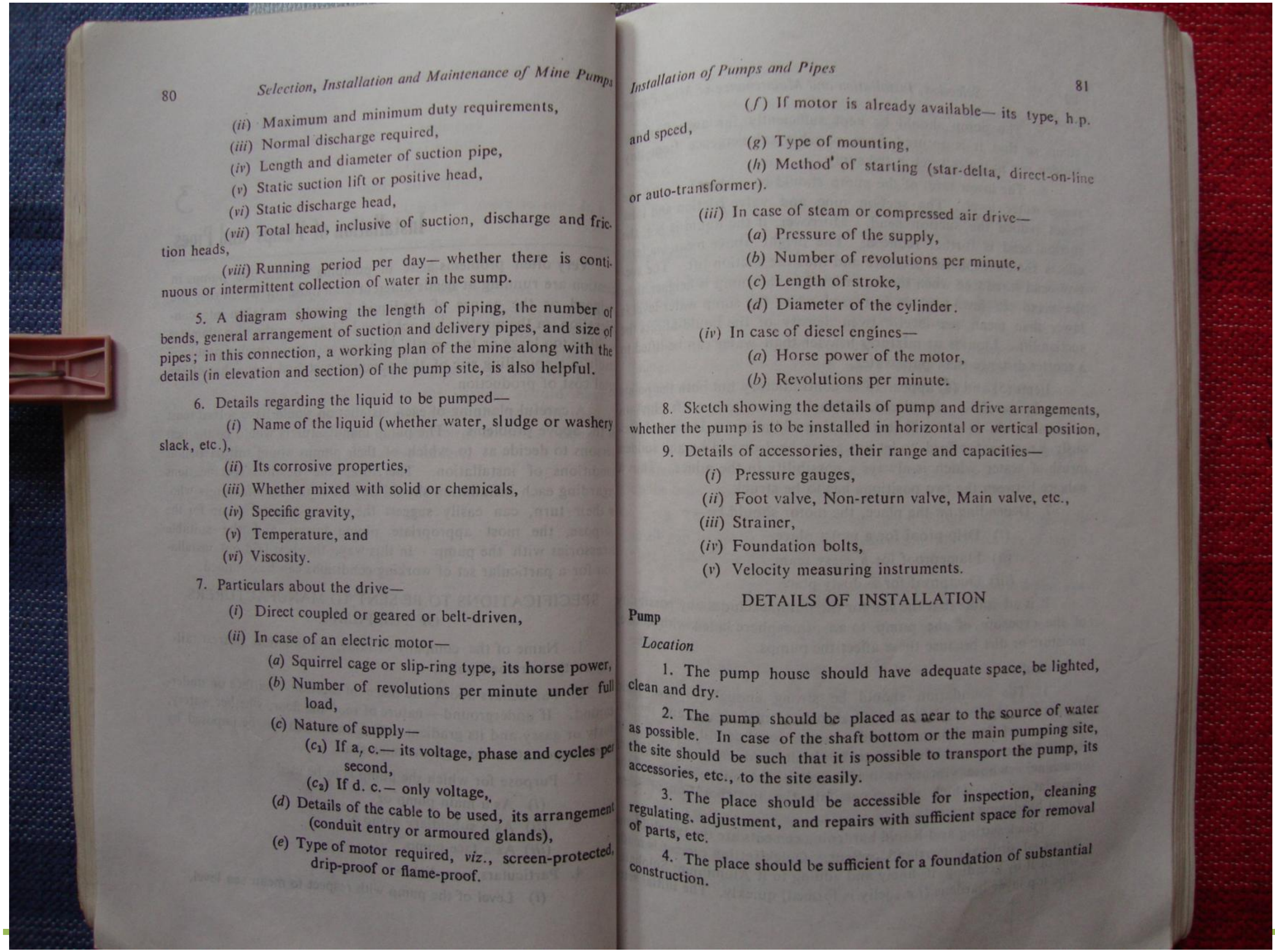
Installation of Pumps and Pipes

Very often problems arise in pumping because the pumps in question are running at heads different from those for which they are designed or the nature of the liquid has not been taken into consideration, or the pipeline has not been laid well, or the pipe diameter is either too large or too small. All these and many similar problems result in a spiralling rise of the pumping cost and hence that of the total cost of production.

A careful planning of each installation would have solved most of the above problems. The pump manufacturers would be the best persons to decide as to which of their pumps would suit particular conditions of installation. Therefore, the detailed specifications regarding each installation should be sent to the manufacturers who, in their turn, can easily suggest the correct type of pump for the purpose, the most appropriate piping layout and the suitable accessories with the pump. In this way, the best laid out installation for a particular set of working conditions can be obtained.

SPECIFICATIONS TO BE SENT TO MANUFACTURERS OF THE PUMPS

1. Name of the company or mine, its situation, nearest railway station or road point,
2. Particulars about the place of erection— surface or underground. If underground— nature of roof and floor, whether watery, dusty or gassy and its gradient. Size limitations can be imposed by the transportation through the mine shaft,
3. Purpose for which the pump is to be used—
   - (i) As a main pump or
   - (ii) As a subsidiary pump or
   - (iii) As a face pump,
4. Particulars regarding—
   - (i) Level of the pump with respect to mean sea level,



(*ii*) Maximum and minimum duty requirements,

(*iii*) Normal discharge required,

(*iv*) Length and diameter of suction pipe,

(*v*) Static suction lift or positive head,

(*vi*) Static discharge head,

(*vii*) Total head, inclusive of suction, discharge and friction heads,

(*viii*) Running period per day— whether there is continuous or intermittent collection of water in the sump.

5. A diagram showing the length of piping, the number of bends, general arrangement of suction and delivery pipes, and size of pipes; in this connection, a working plan of the mine along with the details (in elevation and section) of the pump site, is also helpful.

6. Details regarding the liquid to be pumped—

(*i*) Name of the liquid (whether water, sludge or washery slack, etc.),

(*ii*) Its corrosive properties,

(*iii*) Whether mixed with solid or chemicals,

(*iv*) Specific gravity,

(*v*) Temperature, and

(*vi*) Viscosity.

7. Particulars about the drive—

(*i*) Direct coupled or geared or belt-driven,

(*ii*) In case of an electric motor—

(*a*) Squirrel cage or slip-ring type, its horse power,

(*b*) Number of revolutions per minute under full load,

(*c*) Nature of supply—

(c_1) If a. c.— its voltage, phase and cycles per second,

(c_2) If d. c.— only voltage,

(*d*) Details of the cable to be used, its arrangement (conduit entry or armoured glands),

(*e*) Type of motor required, *viz.*, screen-protected, drip-proof or flame-proof.

(*f*) If motor is already available— its type, h.p. and speed,

(*g*) Type of mounting,

(*h*) Method of starting (star-delta, direct-on-line or auto-transformer).

(*iii*) In case of steam or compressed air drive—

(*a*) Pressure of the supply,

(*b*) Number of revolutions per minute,

(*c*) Length of stroke,

(*d*) Diameter of the cylinder.

(*iv*) In case of diesel engines—

(*a*) Horse power of the motor,

(*b*) Revolutions per minute.

8. Sketch showing the details of pump and drive arrangements, whether the pump is to be installed in horizontal or vertical position,

9. Details of accessories, their range and capacities—

(*i*) Pressure gauges,

(*ii*) Foot valve, Non-return valve, Main valve, etc.,

(*iii*) Strainer,

(*iv*) Foundation bolts,

(*v*) Velocity measuring instruments.

DETAILS OF INSTALLATION

Pump

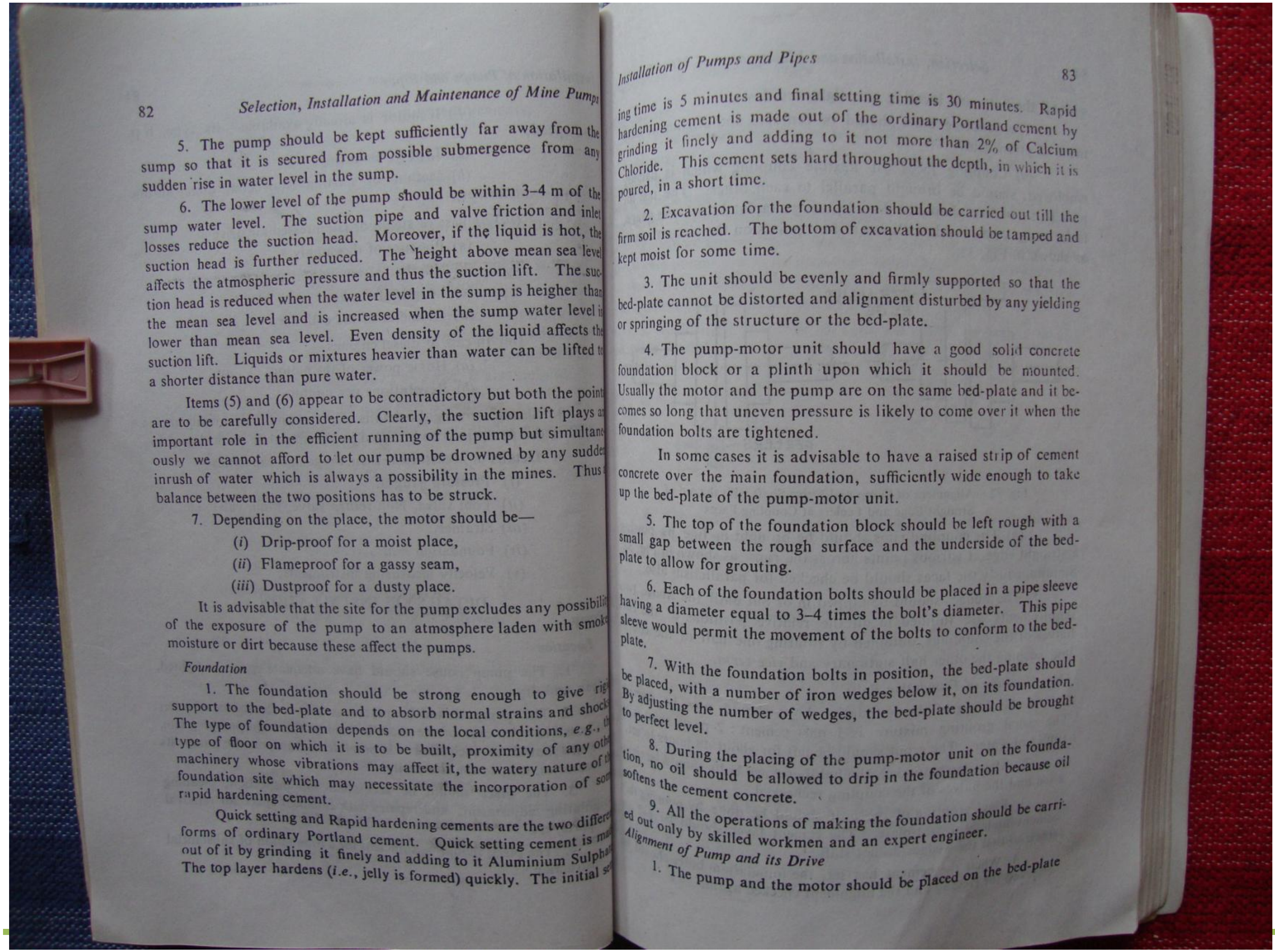
Location

1. The pump house should have adequate space, be lighted, clean and dry.

2. The pump should be placed as near to the source of water as possible. In case of the shaft bottom or the main pumping site, the site should be such that it is possible to transport the pump, its accessories, etc., to the site easily.

3. The place should be accessible for inspection, cleaning regulating, adjustment, and repairs with sufficient space for removal of parts, etc.

4. The place should be sufficient for a foundation of substantial construction.



5. The pump should be kept sufficiently far away from the sump so that it is secured from possible submergence from any sudden rise in water level in the sump.

6. The lower level of the pump should be within 3–4 m of the sump water level. The suction pipe and valve friction and inlet losses reduce the suction head. Moreover, if the liquid is hot, the suction head is further reduced. The height above mean sea level affects the atmospheric pressure and thus the suction lift. The suction head is reduced when the water level in the sump is heigher than the mean sea level and is increased when the sump water level i lower than mean sea level. Even density of the liquid affects the suction lift. Liquids or mixtures heavier than water can be lifted t a shorter distance than pure water.

Items (5) and (6) appear to be contradictory but both the points are to be carefully considered. Clearly, the suction lift plays a important role in the efficient running of the pump but simultane ously we cannot afford to let our pump be drowned by any sudde inrush of water which is always a possibility in the mines. Thus balance between the two positions has to be struck.

7. Depending on the place, the motor should be—

(*i*) Drip-proof for a moist place,

(*ii*) Flameproof for a gassy seam,

(*iii*) Dustproof for a dusty place.

It is advisable that the site for the pump excludes any possibili of the exposure of the pump to an atmosphere laden with smok moisture or dirt because these affect the pumps.

Foundation

1. The foundation should be strong enough to give rig support to the bed-plate and to absorb normal strains and shock The type of foundation depends on the local conditions, *e.g.*, th type of floor on which it is to be built, proximity of any oth machinery whose vibrations may affect it, the watery nature of th foundation site which may necessitate the incorporation of so rapid hardening cement.

Quick setting and Rapid hardening cements are the two differe forms of ordinary Portland cement. Quick setting cement is ma out of it by grinding it finely and adding to it Aluminium Sulpha The top layer hardens (*i.e.*, jelly is formed) quickly. The initial se

ing time is 5 minutes and final setting time is 30 minutes. Rapid hardening cement is made out of the ordinary Portland cement by grinding it finely and adding to it not more than 2% of Calcium Chloride. This cement sets hard throughout the depth, in which it is poured, in a short time.

2. Excavation for the foundation should be carried out till the firm soil is reached. The bottom of excavation should be tamped and kept moist for some time.

3. The unit should be evenly and firmly supported so that the bed-plate cannot be distorted and alignment disturbed by any yielding or springing of the structure or the bed-plate.

4. The pump-motor unit should have a good solid concrete foundation block or a plinth upon which it should be mounted. Usually the motor and the pump are on the same bed-plate and it becomes so long that uneven pressure is likely to come over it when the foundation bolts are tightened.

In some cases it is advisable to have a raised strip of cement concrete over the main foundation, sufficiently wide enough to take up the bed-plate of the pump-motor unit.

5. The top of the foundation block should be left rough with a small gap between the rough surface and the underside of the bed-plate to allow for grouting.

6. Each of the foundation bolts should be placed in a pipe sleeve having a diameter equal to 3–4 times the bolt's diameter. This pipe sleeve would permit the movement of the bolts to conform to the bed-plate.

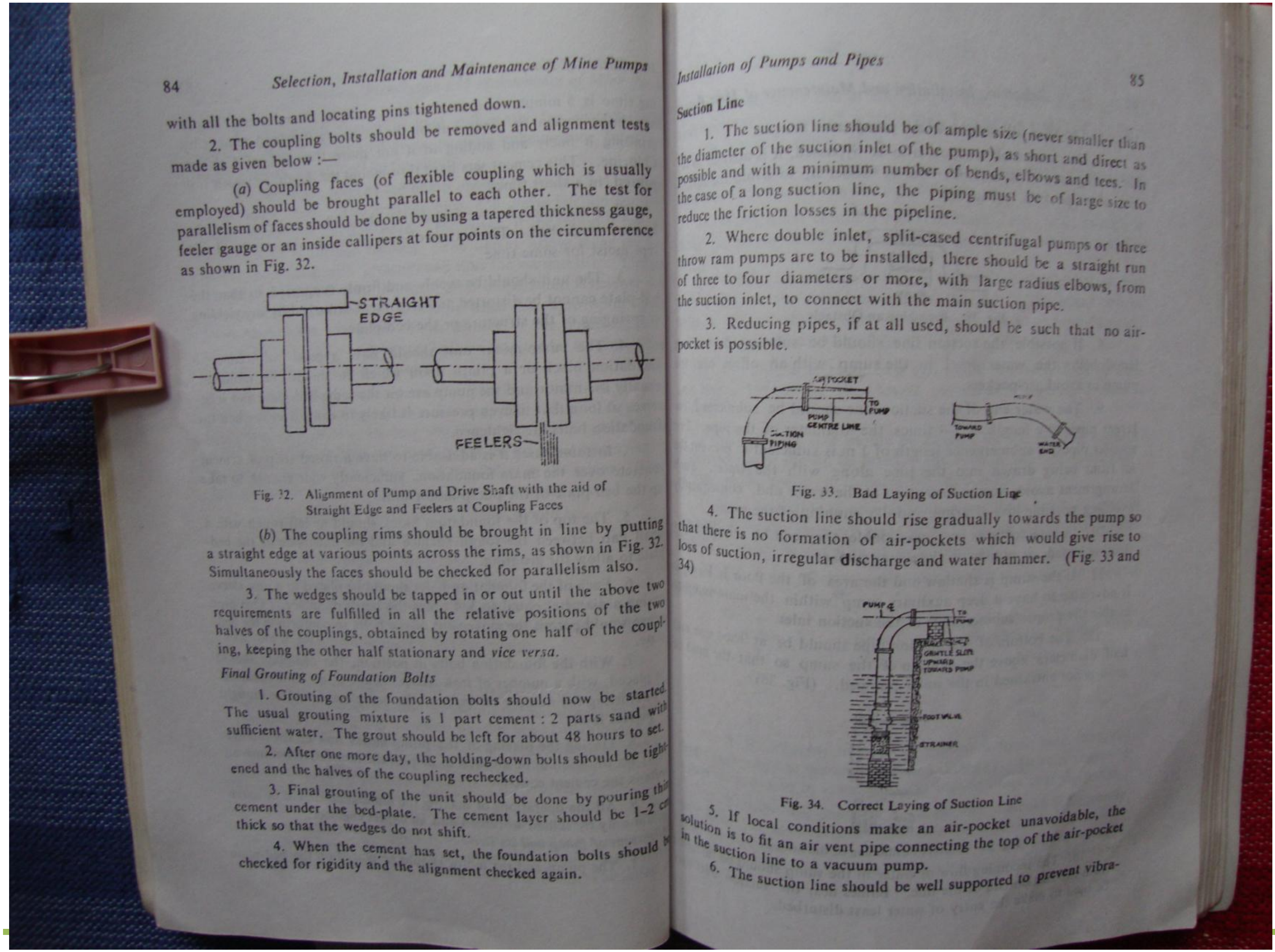
7. With the foundation bolts in position, the bed-plate should be placed, with a number of iron wedges below it, on its foundation. By adjusting the number of wedges, the bed-plate should be brought to perfect level.

8. During the placing of the pump-motor unit on the foundation, no oil should be allowed to drip in the foundation because oil softens the cement concrete.

9. All the operations of making the foundation should be carried out only by skilled workmen and an expert engineer.

Alignment of Pump and its Drive

1. The pump and the motor should be placed on the bed-plate


STRAIGHT EDGE
FEELERS
AIR POCKET
TO PUMP
PUMP CENTRE LINE
SUCTION PIPING
TOWARD PUMP
WATER END
PUMP ℄
TO PUMP
GENTLE SLOPE UPWARD TOWARDS PUMP
FOOT VALVE
STRAINER

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with all the bolts and locating pins tightened down.

2. The coupling bolts should be removed and alignment tests made as given below :—

(*a*) Coupling faces (of flexible coupling which is usually employed) should be brought parallel to each other. The test for parallelism of faces should be done by using a tapered thickness gauge, feeler gauge or an inside callipers at four points on the circumference as shown in Fig. 32.

Fig. 32. Alignment of Pump and Drive Shaft with the aid of Straight Edge and Feelers at Coupling Faces

(*b*) The coupling rims should be brought in line by putting a straight edge at various points across the rims, as shown in Fig. 32. Simultaneously the faces should be checked for parallelism also.

3. The wedges should be tapped in or out until the above two requirements are fulfilled in all the relative positions of the two halves of the couplings, obtained by rotating one half of the coupling, keeping the other half stationary and *vice versa*.

Final Grouting of Foundation Bolts

1. Grouting of the foundation bolts should now be started. The usual grouting mixture is 1 part cement : 2 parts sand with sufficient water. The grout should be left for about 48 hours to set.

2. After one more day, the holding-down bolts should be tight-ened and the halves of the coupling rechecked.

3. Final grouting of the unit should be done by pouring thi cement under the bed-plate. The cement layer should be 1–2 c thick so that the wedges do not shift.

4. When the cement has set, the foundation bolts should b checked for rigidity and the alignment checked again.

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Suction Line

1. The suction line should be of ample size (never smaller than the diameter of the suction inlet of the pump), as short and direct as possible and with a minimum number of bends, elbows and tees. In the case of a long suction line, the piping must be of large size to reduce the friction losses in the pipeline.

2. Where double inlet, split-cased centrifugal pumps or three throw ram pumps are to be installed, there should be a straight run of three to four diameters or more, with large radius elbows, from the suction inlet, to connect with the main suction pipe.

3. Reducing pipes, if at all used, should be such that no air-pocket is possible.

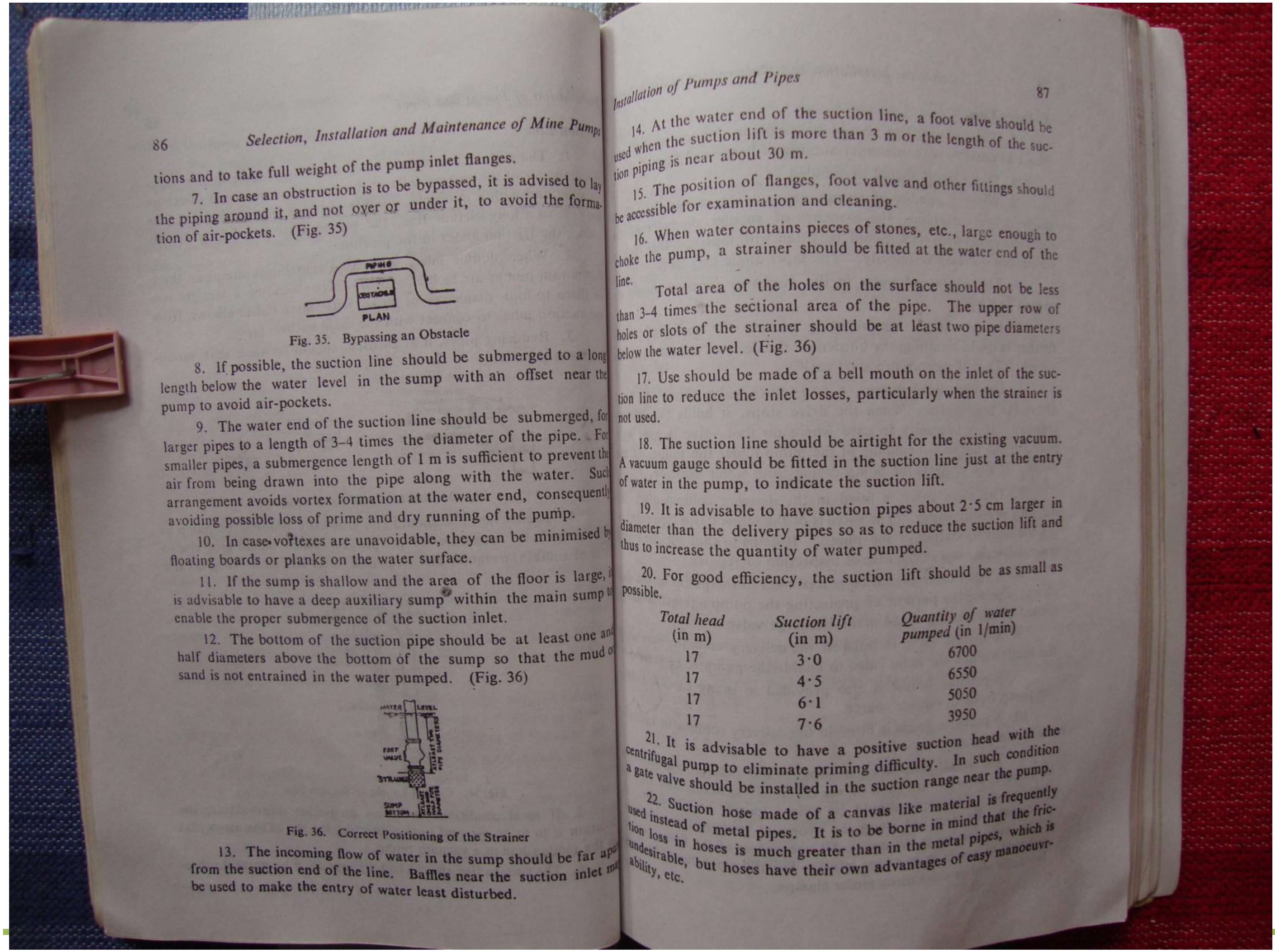
Fig. 33. Bad Laying of Suction Line

4. The suction line should rise gradually towards the pump so that there is no formation of air-pockets which would give rise to loss of suction, irregular discharge and water hammer. (Fig. 33 and 34)

Fig. 34. Correct Laying of Suction Line

5. If local conditions make an air-pocket unavoidable, the solution is to fit an air vent pipe connecting the top of the air-pocket in the suction line to a vacuum pump.

6. The suction line should be well supported to prevent vibra-


PIPING
OBSTACLE
PLAN
WATER
LEVEL
FOOT VALVE
STRAINER
SUMP BOTTOM

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tions and to take full weight of the pump inlet flanges.

7. In case an obstruction is to be bypassed, it is advised to lay the piping around it, and not over or under it, to avoid the forma- tion of air-pockets. (Fig. 35)

Fig. 35. Bypassing an Obstacle

8. If possible, the suction line should be submerged to a long length below the water level in the sump with an offset near the pump to avoid air-pockets.

9. The water end of the suction line should be submerged, for larger pipes to a length of 3–4 times the diameter of the pipe. For smaller pipes, a submergence length of 1 m is sufficient to prevent the air from being drawn into the pipe along with the water. Such arrangement avoids vortex formation at the water end, consequentl avoiding possible loss of prime and dry running of the pump.

10. In case vortexes are unavoidable, they can be minimised b floating boards or planks on the water surface.

11. If the sump is shallow and the area of the floor is large, i is advisable to have a deep auxiliary sump within the main sump t enable the proper submergence of the suction inlet.

12. The bottom of the suction pipe should be at least one an half diameters above the bottom of the sump so that the mud o sand is not entrained in the water pumped. (Fig. 36)

Fig. 36. Correct Positioning of the Strainer

13. The incoming flow of water in the sump should be far ap from the suction end of the line. Baffles near the suction inlet ma be used to make the entry of water least disturbed.

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14. At the water end of the suction line, a foot valve should be used when the suction lift is more than 3 m or the length of the suction piping is near about 30 m.

15. The position of flanges, foot valve and other fittings should be accessible for examination and cleaning.

16. When water contains pieces of stones, etc., large enough to choke the pump, a strainer should be fitted at the water end of the line.

Total area of the holes on the surface should not be less than 3–4 times the sectional area of the pipe. The upper row of holes or slots of the strainer should be at least two pipe diameters below the water level. (Fig. 36)

17. Use should be made of a bell mouth on the inlet of the suction line to reduce the inlet losses, particularly when the strainer is not used.

18. The suction line should be airtight for the existing vacuum. A vacuum gauge should be fitted in the suction line just at the entry of water in the pump, to indicate the suction lift.

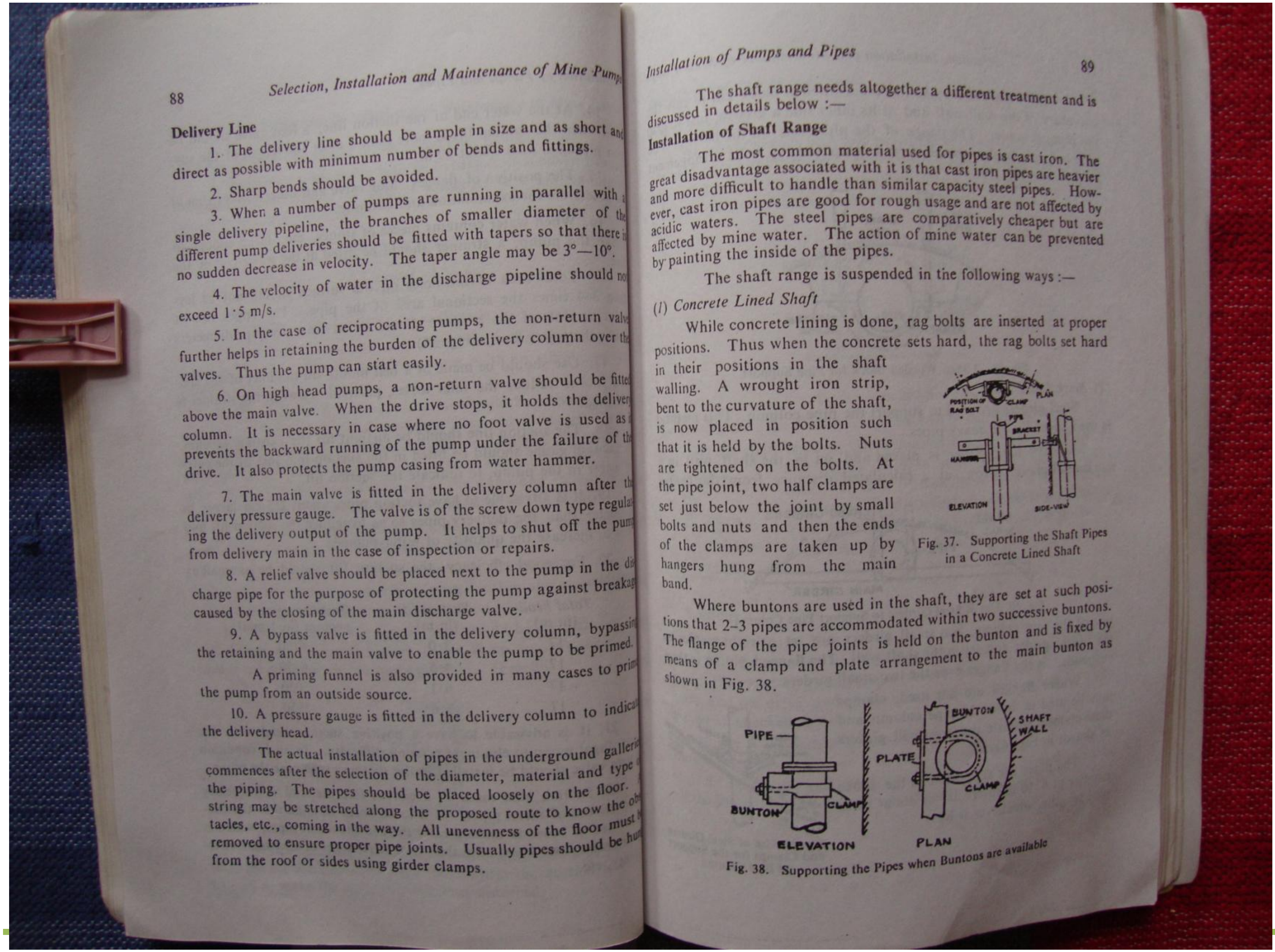
19. It is advisable to have suction pipes about 2·5 cm larger in diameter than the delivery pipes so as to reduce the suction lift and thus to increase the quantity of water pumped.

20. For good efficiency, the suction lift should be as small as possible.

Total head (in m)	*Suction lift* (in m)	*Quantity of water pumped* (in l/min)
17	3·0	6700
17	4·5	6550
17	6·1	5050
17	7·6	3950

21. It is advisable to have a positive suction head with the centrifugal pump to eliminate priming difficulty. In such condition a gate valve should be installed in the suction range near the pump.

22. Suction hose made of a canvas like material is frequently used instead of metal pipes. It is to be borne in mind that the friction loss in hoses is much greater than in the metal pipes, which is undesirable, but hoses have their own advantages of easy manoeuvrability, etc.


POSITION OF RAG BOLT
CLAMP
PLAN
PIPE
BRACKET
HANGER
ELEVATION
SIDE-VIEW
PIPE
BUNTON
PLATE
CLAMP
SHAFT WALL
ELEVATION
PLAN

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Delivery Line

1. The delivery line should be ample in size and as short and direct as possible with minimum number of bends and fittings.

2. Sharp bends should be avoided.

3. When a number of pumps are running in parallel with a single delivery pipeline, the branches of smaller diameter of the different pump deliveries should be fitted with tapers so that there i no sudden decrease in velocity. The taper angle may be 3°—10°.

4. The velocity of water in the discharge pipeline should no exceed 1·5 m/s.

5. In the case of reciprocating pumps, the non-return valv further helps in retaining the burden of the delivery column over th valves. Thus the pump can start easily.

6. On high head pumps, a non-return valve should be fitte above the main valve. When the drive stops, it holds the deliver column. It is necessary in case where no foot valve is used as prevents the backward running of the pump under the failure of th drive. It also protects the pump casing from water hammer.

7. The main valve is fitted in the delivery column after th delivery pressure gauge. The valve is of the screw down type regula ing the delivery output of the pump. It helps to shut off the pum from delivery main in the case of inspection or repairs.

8. A relief valve should be placed next to the pump in the dis charge pipe for the purpose of protecting the pump against breakag caused by the closing of the main discharge valve.

9. A bypass valve is fitted in the delivery column, bypassin the retaining and the main valve to enable the pump to be primed.

A priming funnel is also provided in many cases to prim the pump from an outside source.

10. A pressure gauge is fitted in the delivery column to indica the delivery head.

The actual installation of pipes in the underground galleri commences after the selection of the diameter, material and type the piping. The pipes should be placed loosely on the floor. string may be stretched along the proposed route to know the ob tacles, etc., coming in the way. All unevenness of the floor must removed to ensure proper pipe joints. Usually pipes should be hu from the roof or sides using girder clamps.

Installation of Pumps and Pipes 89

The shaft range needs altogether a different treatment and is discussed in details below :—

Installation of Shaft Range

The most common material used for pipes is cast iron. The great disadvantage associated with it is that cast iron pipes are heavier and more difficult to handle than similar capacity steel pipes. However, cast iron pipes are good for rough usage and are not affected by acidic waters. The steel pipes are comparatively cheaper but are affected by mine water. The action of mine water can be prevented by painting the inside of the pipes.

The shaft range is suspended in the following ways :—

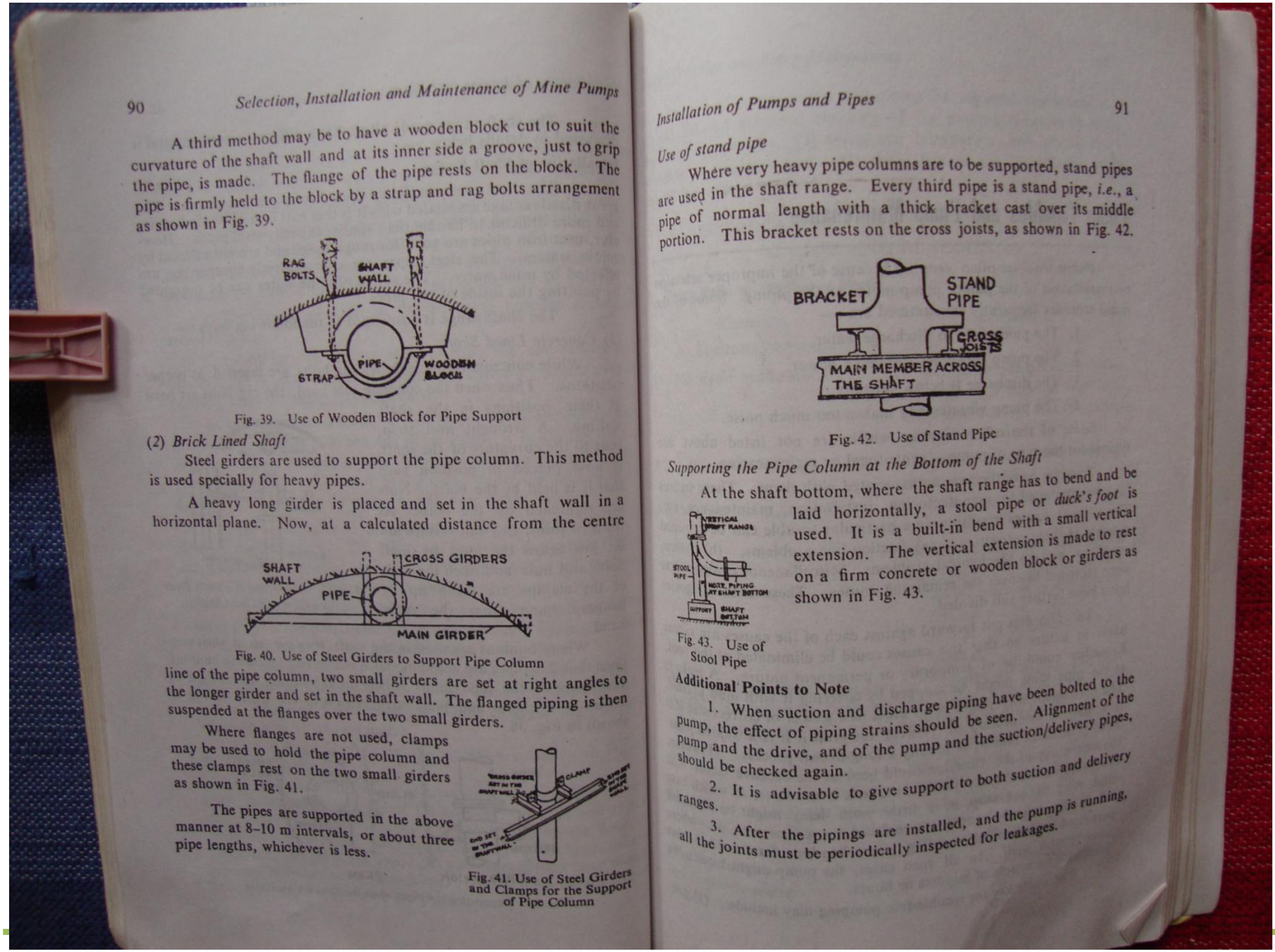
(l) Concrete Lined Shaft

While concrete lining is done, rag bolts are inserted at proper positions. Thus when the concrete sets hard, the rag bolts set hard in their positions in the shaft walling. A wrought iron strip, bent to the curvature of the shaft, is now placed in position such that it is held by the bolts. Nuts are tightened on the bolts. At the pipe joint, two half clamps are set just below the joint by small bolts and nuts and then the ends of the clamps are taken up by hangers hung from the main band.

Fig. 37. Supporting the Shaft Pipes in a Concrete Lined Shaft

Where buntons are used in the shaft, they are set at such positions that 2–3 pipes are accommodated within two successive buntons. The flange of the pipe joints is held on the bunton and is fixed by means of a clamp and plate arrangement to the main bunton as shown in Fig. 38.

Fig. 38. Supporting the Pipes when Buntons are available



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A third method may be to have a wooden block cut to suit the curvature of the shaft wall and at its inner side a groove, just to grip the pipe, is made. The flange of the pipe rests on the block. The pipe is firmly held to the block by a strap and rag bolts arrangement as shown in Fig. 39.

RAG BOLTS
SHAFT WALL
PIPE
WOODEN BLOCK
STRAP

Fig. 39. Use of Wooden Block for Pipe Support

(2) *Brick Lined Shaft*

Steel girders are used to support the pipe column. This method is used specially for heavy pipes.

A heavy long girder is placed and set in the shaft wall in a horizontal plane. Now, at a calculated distance from the centre line of the pipe column, two small girders are set at right angles to the longer girder and set in the shaft wall. The flanged piping is then suspended at the flanges over the two small girders.

SHAFT WALL
CROSS GIRDERS
PIPE
MAIN GIRDER

Fig. 40. Use of Steel Girders to Support Pipe Column

Where flanges are not used, clamps may be used to hold the pipe column and these clamps rest on the two small girders as shown in Fig. 41.

The pipes are supported in the above manner at 8–10 m intervals, or about three pipe lengths, whichever is less.

CROSS GIRDER SET IN THE SHAFT WALL
CLAMP
END SET IN THE SHAFT WALL
END SET IN THE SHAFTWALL

Fig. 41. Use of Steel Girders and Clamps for the Support of Pipe Column

Installation of Pumps and Pipes 91

Use of stand pipe

Where very heavy pipe columns are to be supported, stand pipes are used in the shaft range. Every third pipe is a stand pipe, *i.e.*, a pipe of normal length with a thick bracket cast over its middle portion. This bracket rests on the cross joists, as shown in Fig. 42.

BRACKET
STAND PIPE
CROSS JOISTS
MAIN MEMBER ACROSS THE SHAFT

Fig. 42. Use of Stand Pipe

Supporting the Pipe Column at the Bottom of the Shaft

At the shaft bottom, where the shaft range has to bend and be laid horizontally, a stool pipe or *duck's foot* is used. It is a built-in bend with a small vertical extension. The vertical extension is made to rest on a firm concrete or wooden block or girders as shown in Fig. 43.

VERTICAL SHAFT RANGE
STOOL PIPE
HORZ. PIPING AT SHAFT BOTTOM
SUPPORT
SHAFT BOTTOM

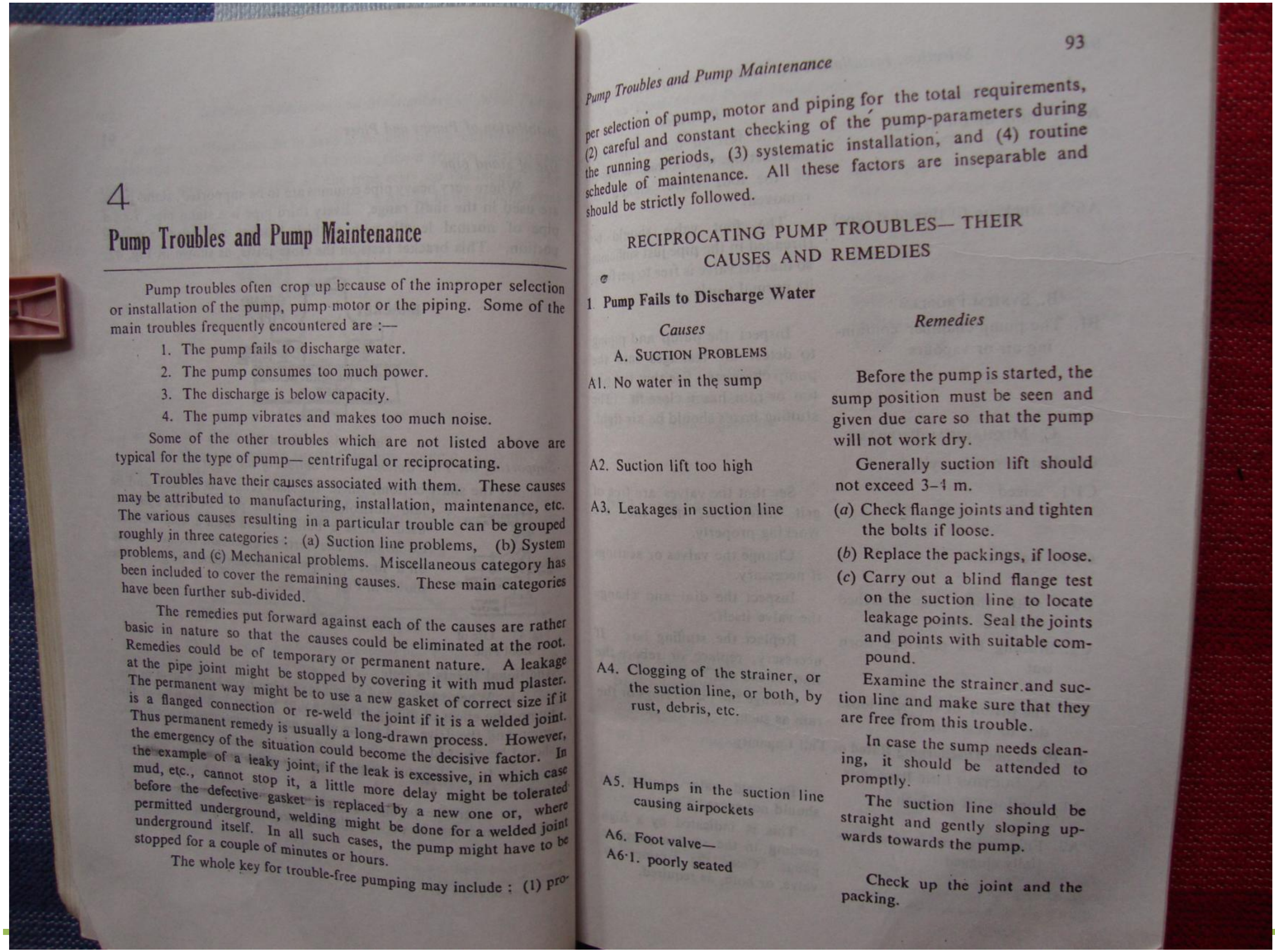
Fig. 43. Use of Stool Pipe

Additional Points to Note

1. When suction and discharge piping have been bolted to the pump, the effect of piping strains should be seen. Alignment of the pump and the drive, and of the pump and the suction/delivery pipes, should be checked again.

2. It is advisable to give support to both suction and delivery ranges.

3. After the pipings are installed, and the pump is running, all the joints must be periodically inspected for leakages.



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Pump Troubles and Pump Maintenance

Pump troubles often crop up because of the improper selection or installation of the pump, pump motor or the piping. Some of the main troubles frequently encountered are :—

1. The pump fails to discharge water.
2. The pump consumes too much power.
3. The discharge is below capacity.
4. The pump vibrates and makes too much noise.

Some of the other troubles which are not listed above are typical for the type of pump— centrifugal or reciprocating.

Troubles have their causes associated with them. These causes may be attributed to manufacturing, installation, maintenance, etc. The various causes resulting in a particular trouble can be grouped roughly in three categories : (a) Suction line problems, (b) System problems, and (c) Mechanical problems. Miscellaneous category has been included to cover the remaining causes. These main categories have been further sub-divided.

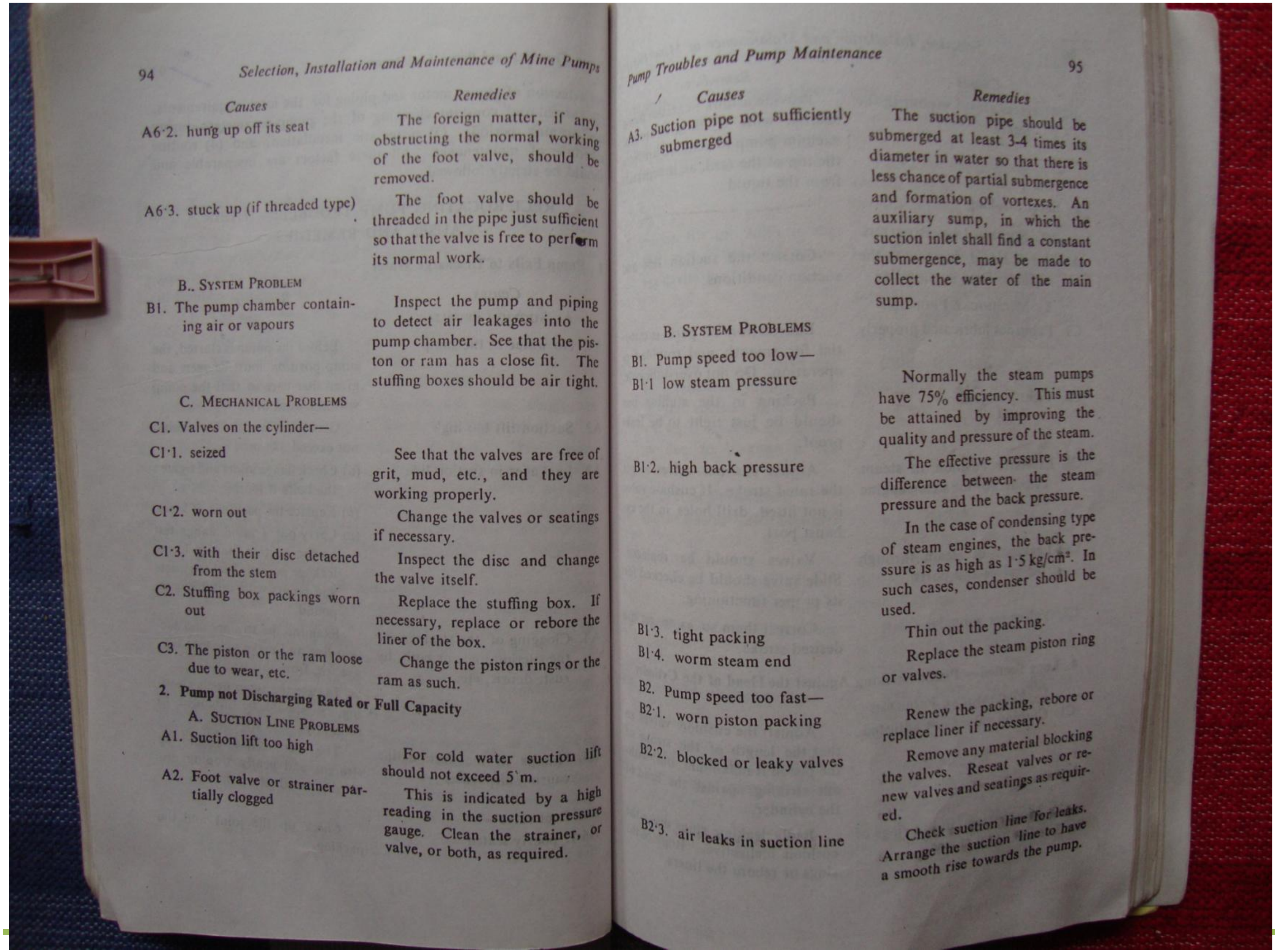
The remedies put forward against each of the causes are rather basic in nature so that the causes could be eliminated at the root. Remedies could be of temporary or permanent nature. A leakage at the pipe joint might be stopped by covering it with mud plaster. The permanent way might be to use a new gasket of correct size if it is a flanged connection or re-weld the joint if it is a welded joint. Thus permanent remedy is usually a long-drawn process. However, the emergency of the situation could become the decisive factor. In the example of a leaky joint, if the leak is excessive, in which case mud, etc., cannot stop it, a little more delay might be tolerated before the defective gasket is replaced by a new one or, where permitted underground, welding might be done for a welded joint underground itself. In all such cases, the pump might have to be stopped for a couple of minutes or hours.

The whole key for trouble-free pumping may include : (1) proper selection of pump, motor and piping for the total requirements, (2) careful and constant checking of the pump-parameters during the running periods, (3) systematic installation, and (4) routine schedule of maintenance. All these factors are inseparable and should be strictly followed.

RECIPROCATING PUMP TROUBLES— THEIR CAUSES AND REMEDIES

1. Pump Fails to Discharge Water

Causes	*Remedies*
A. SUCTION PROBLEMS	
A1. No water in the sump	Before the pump is started, the sump position must be seen and given due care so that the pump will not work dry.
A2. Suction lift too high	Generally suction lift should not exceed 3–4 m.
A3. Leakages in suction line	(*a*) Check flange joints and tighten the bolts if loose. (*b*) Replace the packings, if loose. (*c*) Carry out a blind flange test on the suction line to locate leakage points. Seal the joints and points with suitable compound.
A4. Clogging of the strainer, or the suction line, or both, by rust, debris, etc.	Examine the strainer and suction line and make sure that they are free from this trouble. In case the sump needs cleaning, it should be attended to promptly.
A5. Humps in the suction line causing airpockets	The suction line should be straight and gently sloping upwards towards the pump.
A6. Foot valve—	
A6·1. poorly seated	Check up the joint and the packing.



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Causes	Remedies
A6·2. hung up off its seat	The foreign matter, if any, obstructing the normal working of the foot valve, should be removed.
A6·3. stuck up (if threaded type)	The foot valve should be threaded in the pipe just sufficient so that the valve is free to perform its normal work.
B.. SYSTEM PROBLEM	
B1. The pump chamber containing air or vapours	Inspect the pump and piping to detect air leakages into the pump chamber. See that the piston or ram has a close fit. The stuffing boxes should be air tight.
C. MECHANICAL PROBLEMS	
C1. Valves on the cylinder—	
C1·1. seized	See that the valves are free of grit, mud, etc., and they are working properly.
C1·2. worn out	Change the valves or seatings if necessary.
C1·3. with their disc detached from the stem	Inspect the disc and change the valve itself.
C2. Stuffing box packings worn out	Replace the stuffing box. If necessary, replace or rebore the liner of the box.
C3. The piston or the ram loose due to wear, etc.	Change the piston rings or the ram as such.

2. Pump not Discharging Rated or Full Capacity

Causes	Remedies
A. SUCTION LINE PROBLEMS	
A1. Suction lift too high	For cold water suction lift should not exceed 5 m.
A2. Foot valve or strainer partially clogged	This is indicated by a high reading in the suction pressure gauge. Clean the strainer, or valve, or both, as required.

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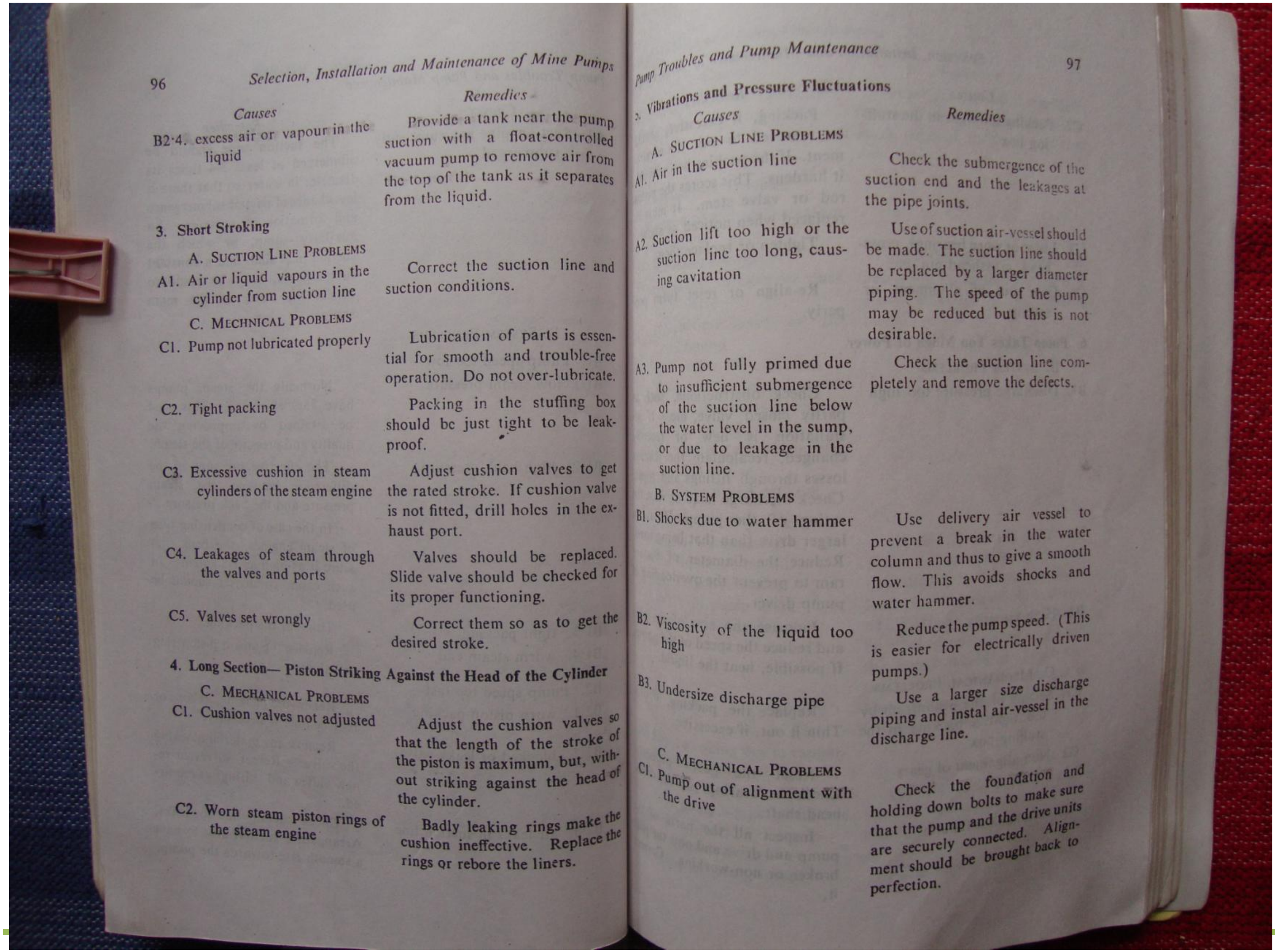
Causes	Remedies
A3. Suction pipe not sufficiently submerged	The suction pipe should be submerged at least 3-4 times its diameter in water so that there is less chance of partial submergence and formation of vortexes. An auxiliary sump, in which the suction inlet shall find a constant submergence, may be made to collect the water of the main sump.
B. SYSTEM PROBLEMS	
B1. Pump speed too low—	
B1·1 low steam pressure	Normally the steam pumps have 75% efficiency. This must be attained by improving the quality and pressure of the steam.
B1·2. high back pressure	The effective pressure is the difference between the steam pressure and the back pressure. In the case of condensing type of steam engines, the back pressure is as high as $1{\cdot}5\ \text{kg/cm}^2$. In such cases, condenser should be used.
B1·3. tight packing	Thin out the packing.
B1·4. worn steam end	Replace the steam piston ring or valves.
B2. Pump speed too fast—	
B2·1. worn piston packing	Renew the packing, rebore or replace liner if necessary.
B2·2. blocked or leaky valves	Remove any material blocking the valves. Reseat valves or renew valves and seatings as required.
B2·3. air leaks in suction line	Check suction line for leaks. Arrange the suction line to have a smooth rise towards the pump.



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Causes	*Remedies*
B2·4. excess air or vapour in the liquid	Provide a tank near the pump suction with a float-controlled vacuum pump to remove air from the top of the tank as it separates from the liquid.

3. Short Stroking

Causes	*Remedies*
A. SUCTION LINE PROBLEMS	
A1. Air or liquid vapours in the cylinder from suction line	Correct the suction line and suction conditions.
C. MECHNICAL PROBLEMS	
C1. Pump not lubricated properly	Lubrication of parts is essential for smooth and trouble-free operation. Do not over-lubricate.
C2. Tight packing	Packing in the stuffing box should be just tight to be leak-proof.
C3. Excessive cushion in steam cylinders of the steam engine	Adjust cushion valves to get the rated stroke. If cushion valve is not fitted, drill holes in the exhaust port.
C4. Leakages of steam through the valves and ports	Valves should be replaced. Slide valve should be checked for its proper functioning.
C5. Valves set wrongly	Correct them so as to get the desired stroke.

4. Long Section— Piston Striking Against the Head of the Cylinder

Causes	*Remedies*
C. MECHANICAL PROBLEMS	
C1. Cushion valves not adjusted	Adjust the cushion valves so that the length of the stroke of the piston is maximum, but, without striking against the head of the cylinder.
C2. Worn steam piston rings of the steam engine	Badly leaking rings make the cushion ineffective. Replace the rings or rebore the liners.

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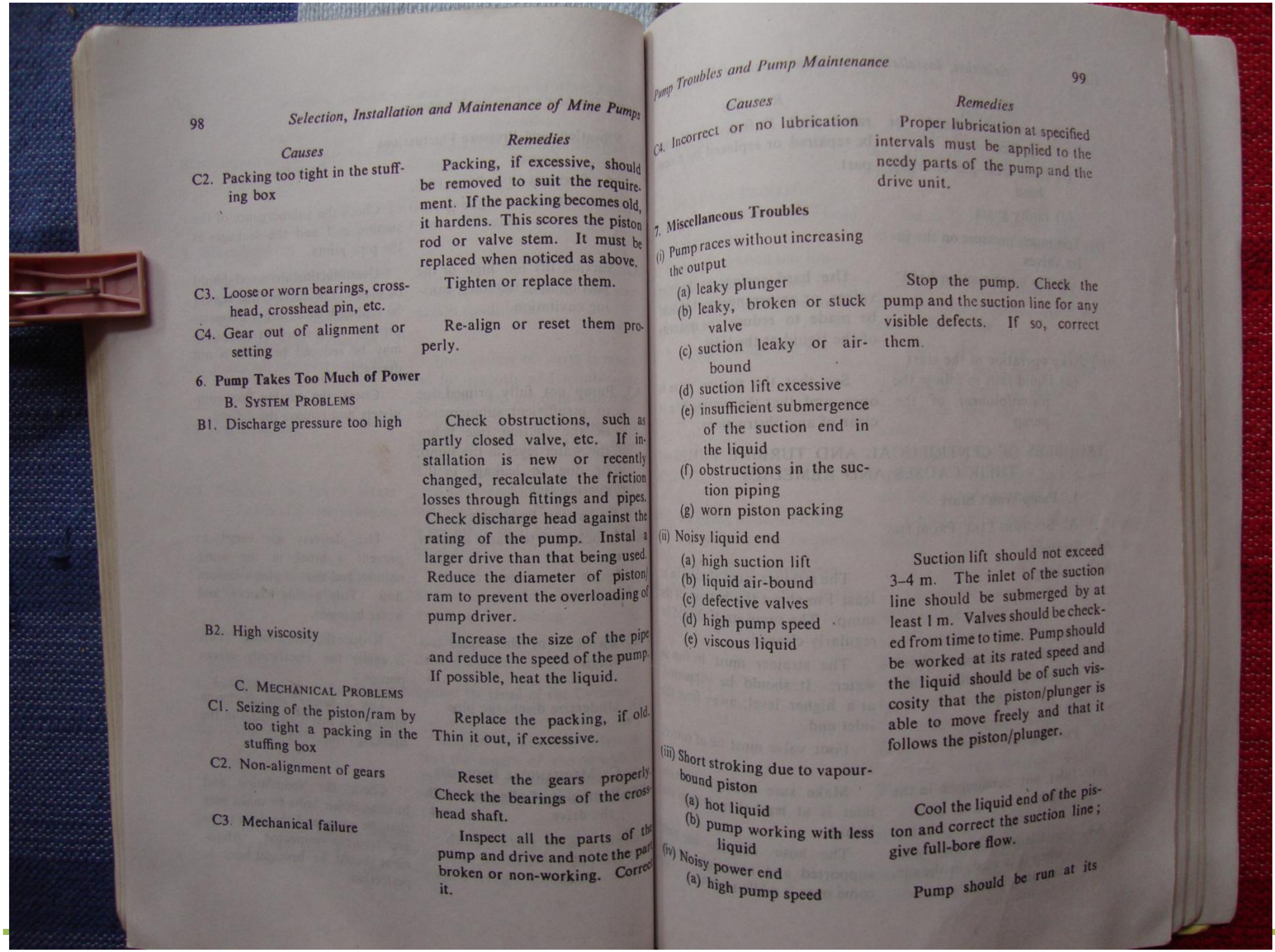
5. Vibrations and Pressure Fluctuations

Causes	*Remedies*
A. SUCTION LINE PROBLEMS	
A1. Air in the suction line	Check the submergence of the suction end and the leakages at the pipe joints.
A2. Suction lift too high or the suction line too long, causing cavitation	Use of suction air-vessel should be made. The suction line should be replaced by a larger diameter piping. The speed of the pump may be reduced but this is not desirable.
A3. Pump not fully primed due to insufficient submergence of the suction line below the water level in the sump, or due to leakage in the suction line.	Check the suction line completely and remove the defects.
B. SYSTEM PROBLEMS	
B1. Shocks due to water hammer	Use delivery air vessel to prevent a break in the water column and thus to give a smooth flow. This avoids shocks and water hammer.
B2. Viscosity of the liquid too high	Reduce the pump speed. (This is easier for electrically driven pumps.)
B3. Undersize discharge pipe	Use a larger size discharge piping and instal air-vessel in the discharge line.
C. MECHANICAL PROBLEMS	
C1. Pump out of alignment with the drive	Check the foundation and holding down bolts to make sure that the pump and the drive units are securely connected. Alignment should be brought back to perfection.



Causes	*Remedies*
C2. Packing too tight in the stuffing box	Packing, if excessive, should be removed to suit the requirement. If the packing becomes old, it hardens. This scores the piston rod or valve stem. It must be replaced when noticed as above.
C3. Loose or worn bearings, crosshead, crosshead pin, etc.	Tighten or replace them.
C4. Gear out of alignment or setting	Re-align or reset them properly.

6. Pump Takes Too Much of Power

B. SYSTEM PROBLEMS

Causes	*Remedies*
B1. Discharge pressure too high	Check obstructions, such as partly closed valve, etc. If installation is new or recently changed, recalculate the friction losses through fittings and pipes. Check discharge head against the rating of the pump. Instal a larger drive than that being used. Reduce the diameter of piston/ram to prevent the overloading of pump driver.
B2. High viscosity	Increase the size of the pipe and reduce the speed of the pump. If possible, heat the liquid.

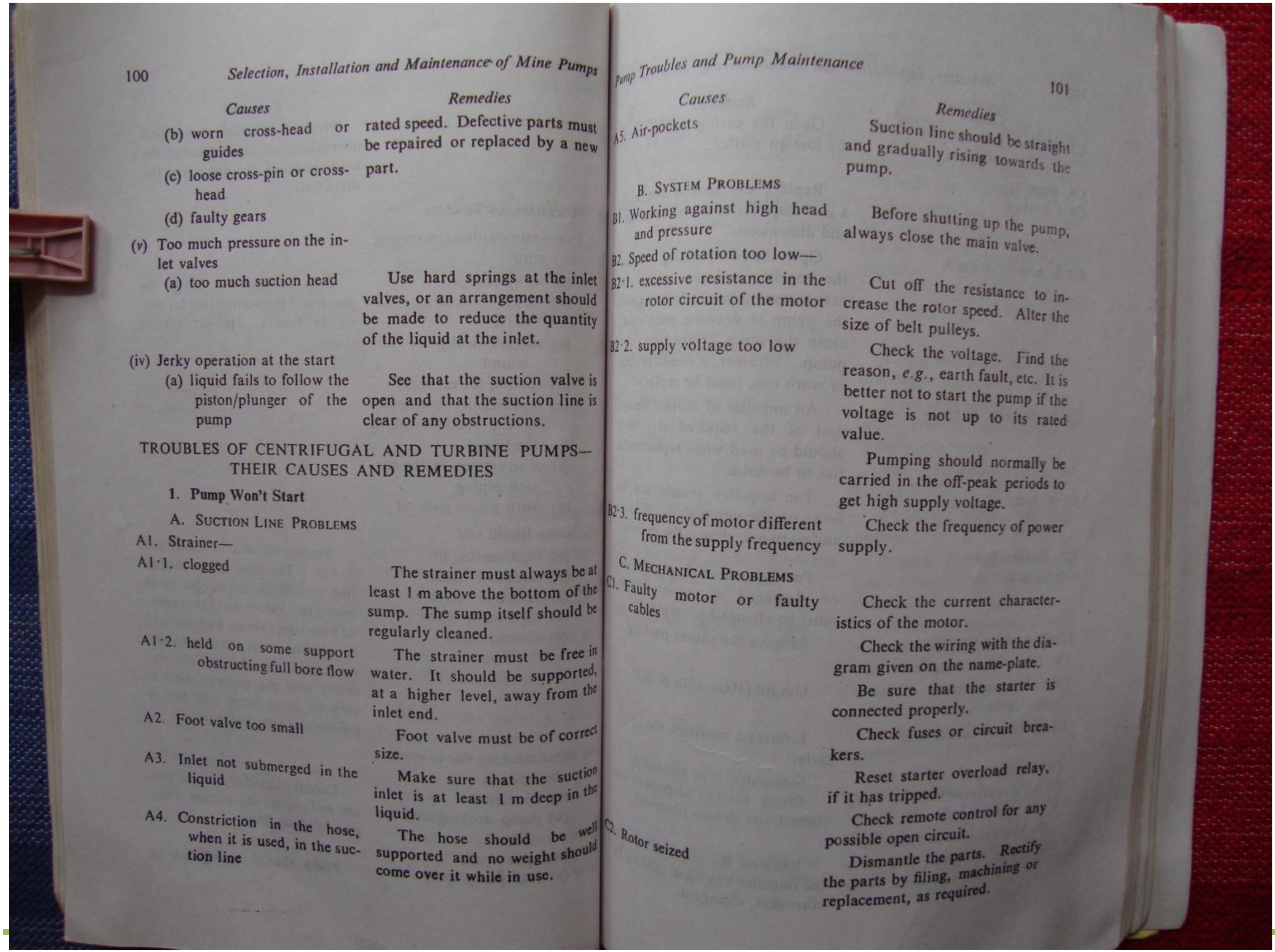
C. MECHANICAL PROBLEMS

Causes	*Remedies*
C1. Seizing of the piston/ram by too tight a packing in the stuffing box	Replace the packing, if old. Thin it out, if excessive.
C2. Non-alignment of gears	Reset the gears properly. Check the bearings of the cross head shaft.
C3. Mechanical failure	Inspect all the parts of th pump and drive and note the par broken or non-working. Correc it.

Causes	*Remedies*
C4. Incorrect or no lubrication	Proper lubrication at specified intervals must be applied to the needy parts of the pump and the drive unit.

7. Miscellaneous Troubles

Causes	*Remedies*
(i) Pump races without increasing the output (a) leaky plunger (b) leaky, broken or stuck valve (c) suction leaky or air-bound (d) suction lift excessive (e) insufficient submergence of the suction end in the liquid (f) obstructions in the suction piping (g) worn piston packing	Stop the pump. Check the pump and the suction line for any visible defects. If so, correct them.
(ii) Noisy liquid end (a) high suction lift (b) liquid air-bound (c) defective valves (d) high pump speed (e) viscous liquid	Suction lift should not exceed 3–4 m. The inlet of the suction line should be submerged by at least 1 m. Valves should be checked from time to time. Pump should be worked at its rated speed and the liquid should be of such viscosity that the piston/plunger is able to move freely and that it follows the piston/plunger.
(iii) Short stroking due to vapour-bound piston (a) hot liquid (b) pump working with less liquid	Cool the liquid end of the piston and correct the suction line; give full-bore flow.
(iv) Noisy power end (a) high pump speed	Pump should be run at its



Causes	*Remedies*
(b) worn cross-head or guides (c) loose cross-pin or cross-head (d) faulty gears	rated speed. Defective parts must be repaired or replaced by a new part.
(*v*) Too much pressure on the inlet valves	
(a) too much suction head	Use hard springs at the inlet valves, or an arrangement should be made to reduce the quantity of the liquid at the inlet.
(iv) Jerky operation at the start	
(a) liquid fails to follow the piston/plunger of the pump	See that the suction valve is open and that the suction line is clear of any obstructions.

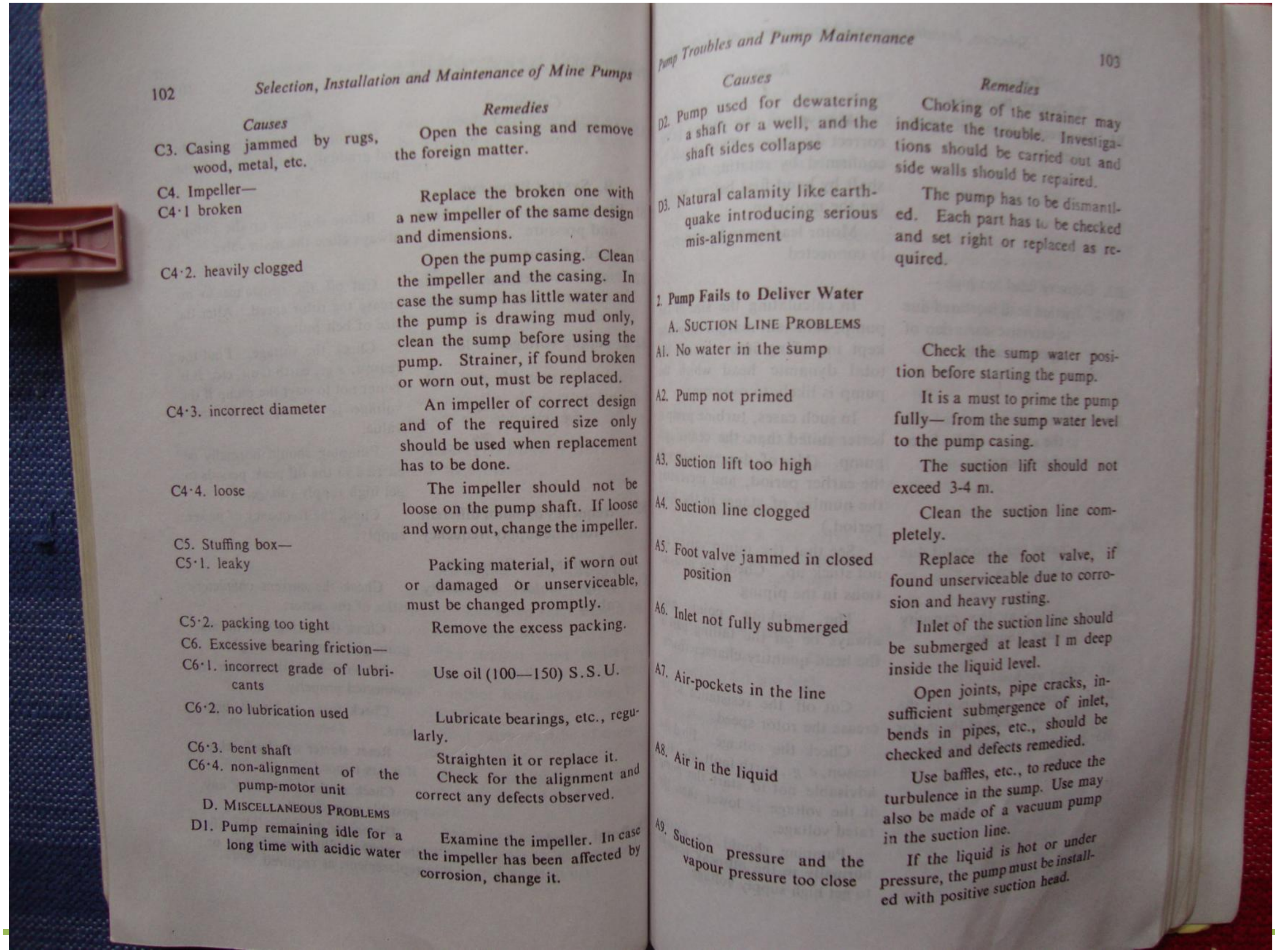
TROUBLES OF CENTRIFUGAL AND TURBINE PUMPS—THEIR CAUSES AND REMEDIES

1. Pump Won't Start

A. Suction Line Problems

A1. Strainer—	
A1·1. clogged	The strainer must always be at least 1 m above the bottom of the sump. The sump itself should be regularly cleaned.
A1·2. held on some support obstructing full bore flow	The strainer must be free in water. It should be supported, at a higher level, away from the inlet end.
A2. Foot valve too small	Foot valve must be of correct size.
A3. Inlet not submerged in the liquid	Make sure that the suction inlet is at least 1 m deep in the liquid.
A4. Constriction in the hose, when it is used, in the suction line	The hose should be well supported and no weight should come over it while in use.

Causes	*Remedies*
A5. Air-pockets	Suction line should be straight and gradually rising towards the pump.
B. System Problems	
B1. Working against high head and pressure	Before shutting up the pump, always close the main valve.
B2. Speed of rotation too low—	
B2·1. excessive resistance in the rotor circuit of the motor	Cut off the resistance to increase the rotor speed. Alter the size of belt pulleys.
B2·2. supply voltage too low	Check the voltage. Find the reason, *e.g.*, earth fault, etc. It is better not to start the pump if the voltage is not up to its rated value. Pumping should normally be carried in the off-peak periods to get high supply voltage.
B2·3. frequency of motor different from the supply frequency	Check the frequency of power supply.
C. Mechanical Problems	
C1. Faulty motor or faulty cables	Check the current characteristics of the motor. Check the wiring with the diagram given on the name-plate. Be sure that the starter is connected properly. Check fuses or circuit breakers. Reset starter overload relay, if it has tripped. Check remote control for any possible open circuit.
C2. Rotor seized	Dismantle the parts. Rectify the parts by filing, machining or replacement, as required.



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Causes	*Remedies*
C3. Casing jammed by rugs, wood, metal, etc.	Open the casing and remove the foreign matter.
C4. Impeller—	
C4·1 broken	Replace the broken one with a new impeller of the same design and dimensions.
C4·2. heavily clogged	Open the pump casing. Clean the impeller and the casing. In case the sump has little water and the pump is drawing mud only, clean the sump before using the pump. Strainer, if found broken or worn out, must be replaced.
C4·3. incorrect diameter	An impeller of correct design and of the required size only should be used when replacement has to be done.
C4·4. loose	The impeller should not be loose on the pump shaft. If loose and worn out, change the impeller.
C5. Stuffing box—	
C5·1. leaky	Packing material, if worn out or damaged or unserviceable, must be changed promptly.
C5·2. packing too tight	Remove the excess packing.
C6. Excessive bearing friction—	
C6·1. incorrect grade of lubricants	Use oil (100—150) S.S.U.
C6·2. no lubrication used	Lubricate bearings, etc., regularly.
C6·3. bent shaft	Straighten it or replace it.
C6·4. non-alignment of the pump-motor unit	Check for the alignment and correct any defects observed.
D. MISCELLANEOUS PROBLEMS	
D1. Pump remaining idle for a long time with acidic water	Examine the impeller. In case the impeller has been affected by corrosion, change it.

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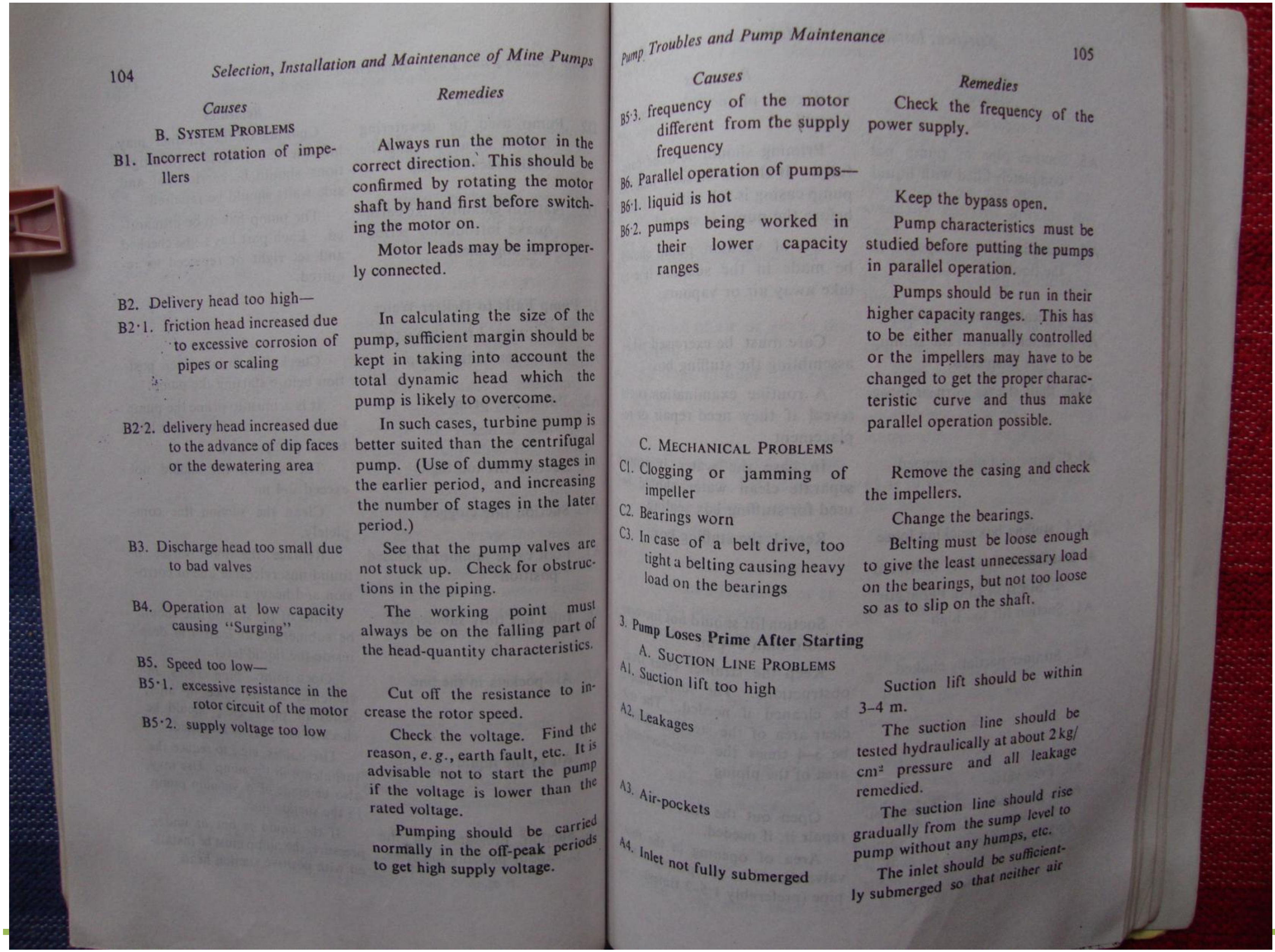
Causes	*Remedies*
D2. Pump used for dewatering a shaft or a well, and the shaft sides collapse	Choking of the strainer may indicate the trouble. Investigations should be carried out and side walls should be repaired.
D3. Natural calamity like earthquake introducing serious mis-alignment	The pump has to be dismantled. Each part has to be checked and set right or replaced as required.

2. Pump Fails to Deliver Water

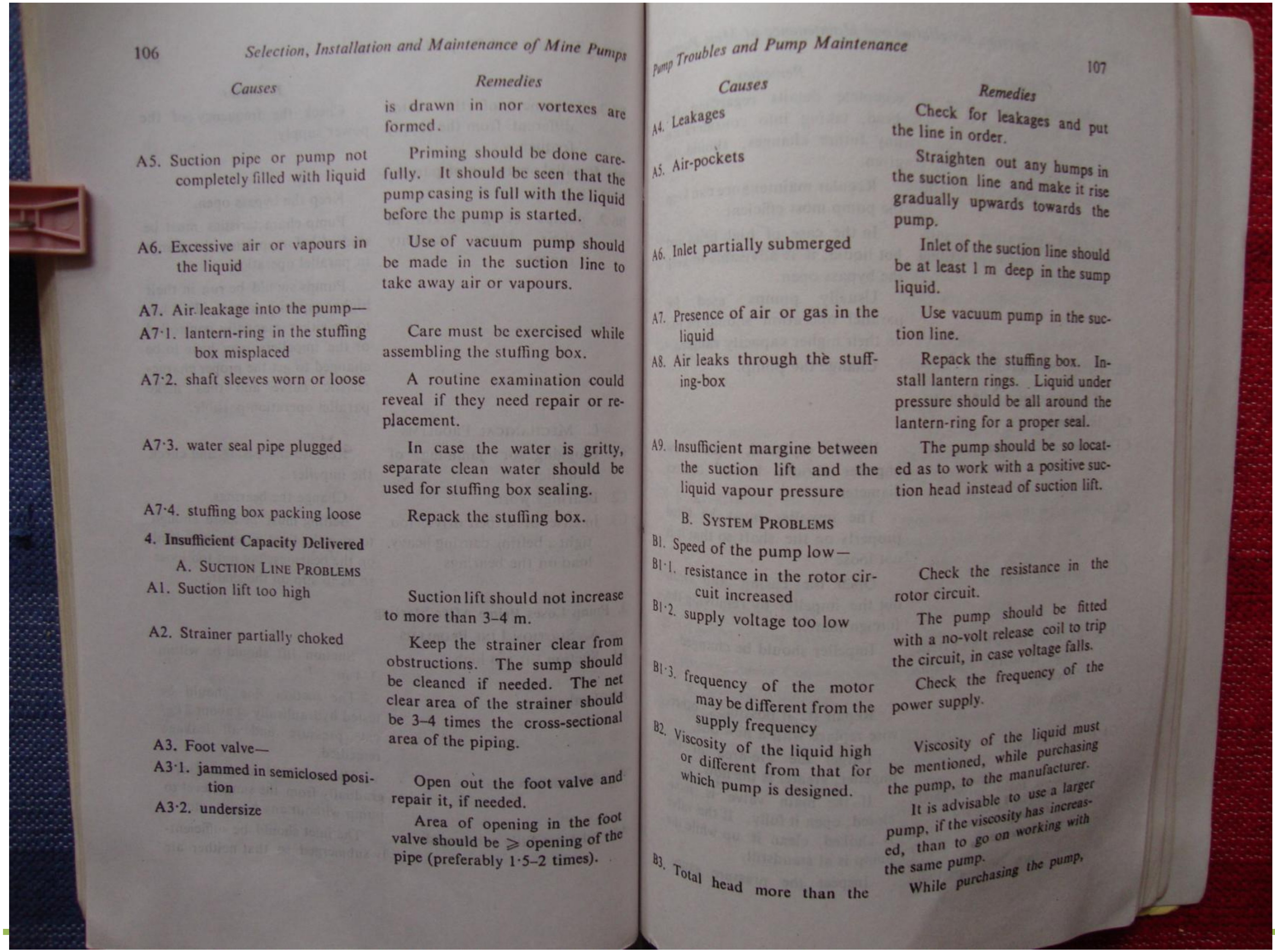
A. SUCTION LINE PROBLEMS

A1. No water in the sump	Check the sump water position before starting the pump.
A2. Pump not primed	It is a must to prime the pump fully— from the sump water level to the pump casing.
A3. Suction lift too high	The suction lift should not exceed 3-4 m.
A4. Suction line clogged	Clean the suction line completely.
A5. Foot valve jammed in closed position	Replace the foot valve, if found unserviceable due to corrosion and heavy rusting.
A6. Inlet not fully submerged	Inlet of the suction line should be submerged at least 1 m deep inside the liquid level.
A7. Air-pockets in the line	Open joints, pipe cracks, insufficient submergence of inlet, bends in pipes, etc., should be checked and defects remedied.
A8. Air in the liquid	Use baffles, etc., to reduce the turbulence in the sump. Use may also be made of a vacuum pump in the suction line.
A9. Suction pressure and the vapour pressure too close	If the liquid is hot or under pressure, the pump must be installed with positive suction head.



Causes	*Remedies*
B. SYSTEM PROBLEMS	
B1. Incorrect rotation of impellers	Always run the motor in the correct direction. This should be confirmed by rotating the motor shaft by hand first before switching the motor on. Motor leads may be improperly connected.
B2. Delivery head too high—	
B2·1. friction head increased due to excessive corrosion of pipes or scaling	In calculating the size of the pump, sufficient margin should be kept in taking into account the total dynamic head which the pump is likely to overcome.
B2·2. delivery head increased due to the advance of dip faces or the dewatering area	In such cases, turbine pump is better suited than the centrifugal pump. (Use of dummy stages in the earlier period, and increasing the number of stages in the later period.)
B3. Discharge head too small due to bad valves	See that the pump valves are not stuck up. Check for obstructions in the piping.
B4. Operation at low capacity causing "Surging"	The working point must always be on the falling part of the head-quantity characteristics.
B5. Speed too low—	
B5·1. excessive resistance in the rotor circuit of the motor	Cut off the resistance to increase the rotor speed.
B5·2. supply voltage too low	Check the voltage. Find the reason, *e.g.*, earth fault, etc. It is advisable not to start the pump if the voltage is lower than the rated voltage. Pumping should be carried normally in the off-peak periods to get high supply voltage.

Causes	*Remedies*
B5·3. frequency of the motor different from the supply frequency	Check the frequency of the power supply.
B6. Parallel operation of pumps—	
B6·1. liquid is hot	Keep the bypass open.
B6·2. pumps being worked in their lower capacity ranges	Pump characteristics must be studied before putting the pumps in parallel operation. Pumps should be run in their higher capacity ranges. This has to be either manually controlled or the impellers may have to be changed to get the proper characteristic curve and thus make parallel operation possible.
C. MECHANICAL PROBLEMS	
C1. Clogging or jamming of impeller	Remove the casing and check the impellers.
C2. Bearings worn	Change the bearings.
C3. In case of a belt drive, too tight a belting causing heavy load on the bearings	Belting must be loose enough to give the least unnecessary load on the bearings, but not too loose so as to slip on the shaft.
3. Pump Loses Prime After Starting	
A. SUCTION LINE PROBLEMS	
A1. Suction lift too high	Suction lift should be within 3–4 m.
A2. Leakages	The suction line should be tested hydraulically at about 2 kg/cm^2 pressure and all leakage remedied.
A3. Air-pockets	The suction line should rise gradually from the sump level to pump without any humps, etc.
A4. Inlet not fully submerged	The inlet should be sufficiently submerged so that neither air



Causes	*Remedies*
	is drawn in nor vortexes are formed.
A5. Suction pipe or pump not completely filled with liquid	Priming should be done carefully. It should be seen that the pump casing is full with the liquid before the pump is started.
A6. Excessive air or vapours in the liquid	Use of vacuum pump should be made in the suction line to take away air or vapours.
A7. Air leakage into the pump—	
A7·1. lantern-ring in the stuffing box misplaced	Care must be exercised while assembling the stuffing box.
A7·2. shaft sleeves worn or loose	A routine examination could reveal if they need repair or replacement.
A7·3. water seal pipe plugged	In case the water is gritty, separate clean water should be used for stuffing box sealing.
A7·4. stuffing box packing loose	Repack the stuffing box.

4. Insufficient Capacity Delivered

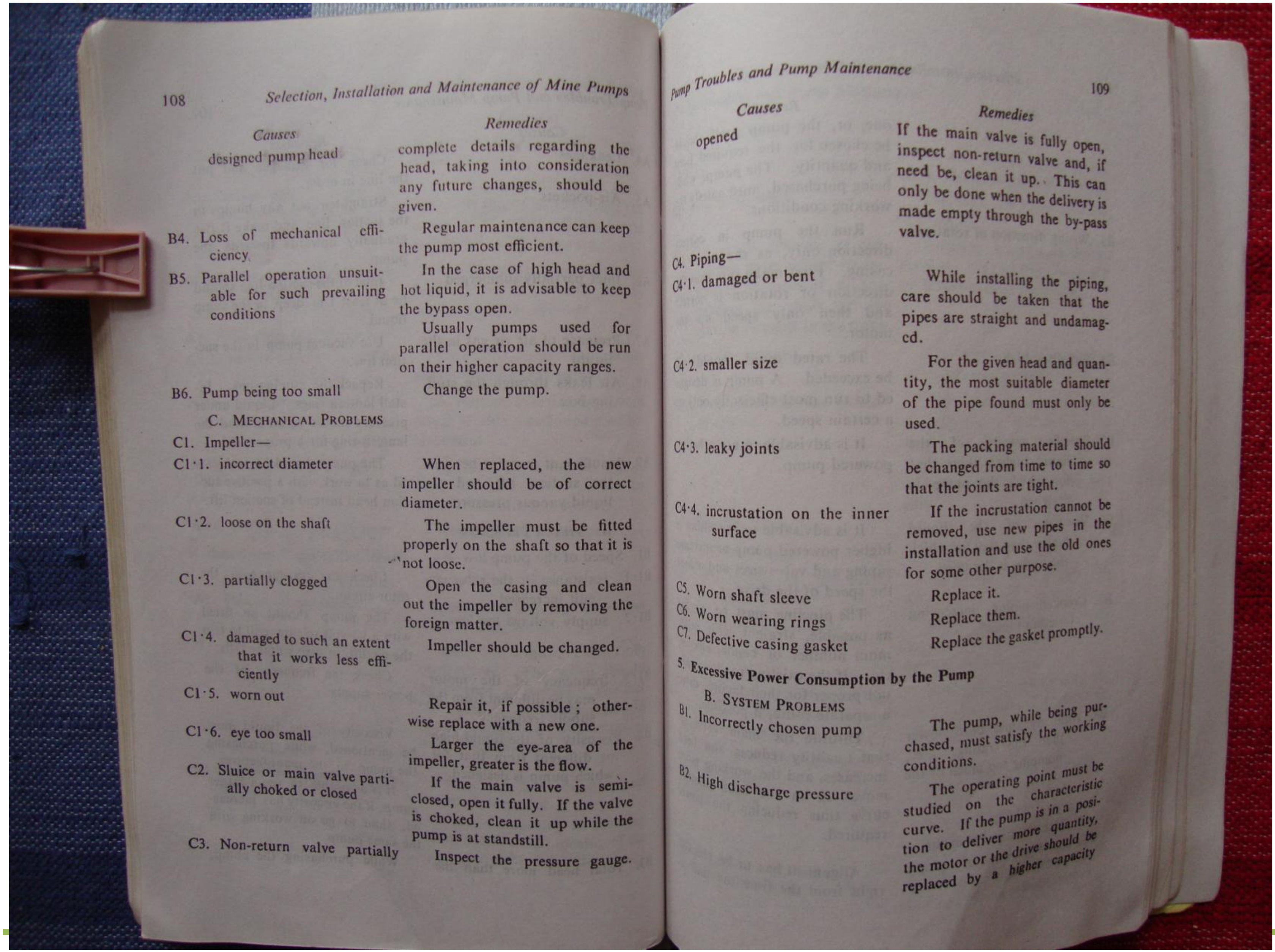
A. Suction Line Problems

A1. Suction lift too high	Suction lift should not increase to more than 3–4 m.
A2. Strainer partially choked	Keep the strainer clear from obstructions. The sump should be cleaned if needed. The net clear area of the strainer should be 3–4 times the cross-sectional area of the piping.
A3. Foot valve—	
A3·1. jammed in semiclosed position	Open out the foot valve and repair it, if needed.
A3·2. undersize	Area of opening in the foot valve should be ⩾ opening of the pipe (preferably 1·5–2 times).

Causes	*Remedies*
A4. Leakages	Check for leakages and put the line in order.
A5. Air-pockets	Straighten out any humps in the suction line and make it rise gradually upwards towards the pump.
A6. Inlet partially submerged	Inlet of the suction line should be at least 1 m deep in the sump liquid.
A7. Presence of air or gas in the liquid	Use vacuum pump in the suction line.
A8. Air leaks through the stuffing-box	Repack the stuffing box. Install lantern rings. Liquid under pressure should be all around the lantern-ring for a proper seal.
A9. Insufficient margin between the suction lift and the liquid vapour pressure	The pump should be so located as to work with a positive suction head instead of suction lift.

B. System Problems

B1. Speed of the pump low—	
B1·1. resistance in the rotor circuit increased	Check the resistance in the rotor circuit.
B1·2. supply voltage too low	The pump should be fitted with a no-volt release coil to trip the circuit, in case voltage falls.
B1·3. frequency of the motor may be different from the supply frequency	Check the frequency of the power supply.
B2. Viscosity of the liquid high or different from that for which pump is designed.	Viscosity of the liquid must be mentioned, while purchasing the pump, to the manufacturer. It is advisable to use a larger pump, if the viscosity has increased, than to go on working with the same pump.
B3. Total head more than the	While purchasing the pump,



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Causes	*Remedies*
designed pump head	complete details regarding the head, taking into consideration any future changes, should be given.
B4. Loss of mechanical efficiency	Regular maintenance can keep the pump most efficient.
B5. Parallel operation unsuitable for such prevailing conditions	In the case of high head and hot liquid, it is advisable to keep the bypass open. Usually pumps used for parallel operation should be run on their higher capacity ranges.
B6. Pump being too small	Change the pump.
C. MECHANICAL PROBLEMS	
C1. Impeller—	
C1·1. incorrect diameter	When replaced, the new impeller should be of correct diameter.
C1·2. loose on the shaft	The impeller must be fitted properly on the shaft so that it is not loose.
C1·3. partially clogged	Open the casing and clean out the impeller by removing the foreign matter.
C1·4. damaged to such an extent that it works less efficiently	Impeller should be changed.
C1·5. worn out	Repair it, if possible; otherwise replace with a new one.
C1·6. eye too small	Larger the eye-area of the impeller, greater is the flow.
C2. Sluice or main valve partially choked or closed	If the main valve is semi-closed, open it fully. If the valve is choked, clean it up while the pump is at standstill.
C3. Non-return valve partially	Inspect the pressure gauge.

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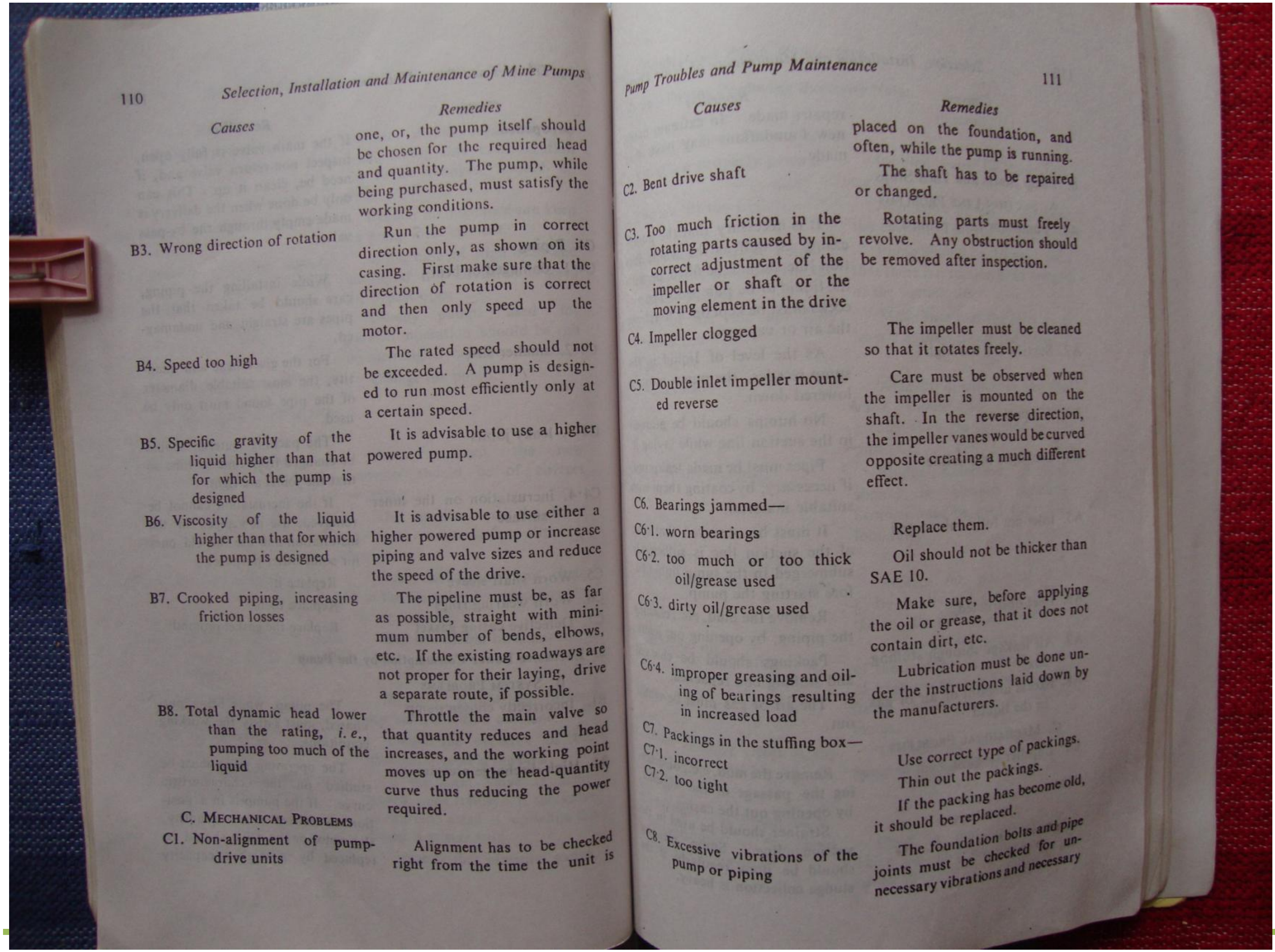
Causes	*Remedies*
opened	If the main valve is fully open, inspect non-return valve and, if need be, clean it up. This can only be done when the delivery is made empty through the by-pass valve.
C4. Piping—	
C4·1. damaged or bent	While installing the piping, care should be taken that the pipes are straight and undamaged.
C4·2. smaller size	For the given head and quantity, the most suitable diameter of the pipe found must only be used.
C4·3. leaky joints	The packing material should be changed from time to time so that the joints are tight.
C4·4. incrustation on the inner surface	If the incrustation cannot be removed, use new pipes in the installation and use the old ones for some other purpose.
C5. Worn shaft sleeve	Replace it.
C6. Worn wearing rings	Replace them.
C7. Defective casing gasket	Replace the gasket promptly.

5. Excessive Power Consumption by the Pump

B. SYSTEM PROBLEMS

B1. Incorrectly chosen pump	The pump, while being purchased, must satisfy the working conditions.
B2. High discharge pressure	The operating point must be studied on the characteristic curve. If the pump is in a position to deliver more quantity, the motor or the drive should be replaced by a higher capacity



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Causes	*Remedies*
	one, or, the pump itself should be chosen for the required head and quantity. The pump, while being purchased, must satisfy the working conditions.
B3. Wrong direction of rotation	Run the pump in correct direction only, as shown on its casing. First make sure that the direction of rotation is correct and then only speed up the motor.
B4. Speed too high	The rated speed should not be exceeded. A pump is designed to run most efficiently only at a certain speed.
B5. Specific gravity of the liquid higher than that for which the pump is designed	It is advisable to use a higher powered pump.
B6. Viscosity of the liquid higher than that for which the pump is designed	It is advisable to use either a higher powered pump or increase piping and valve sizes and reduce the speed of the drive.
B7. Crooked piping, increasing friction losses	The pipeline must be, as far as possible, straight with minimum number of bends, elbows, etc. If the existing roadways are not proper for their laying, drive a separate route, if possible.
B8. Total dynamic head lower than the rating, *i.e.*, pumping too much of the liquid	Throttle the main valve so that quantity reduces and head increases, and the working point moves up on the head-quantity curve thus reducing the power required.
C. MECHANICAL PROBLEMS	
C1. Non-alignment of pump-drive units	Alignment has to be checked right from the time the unit is

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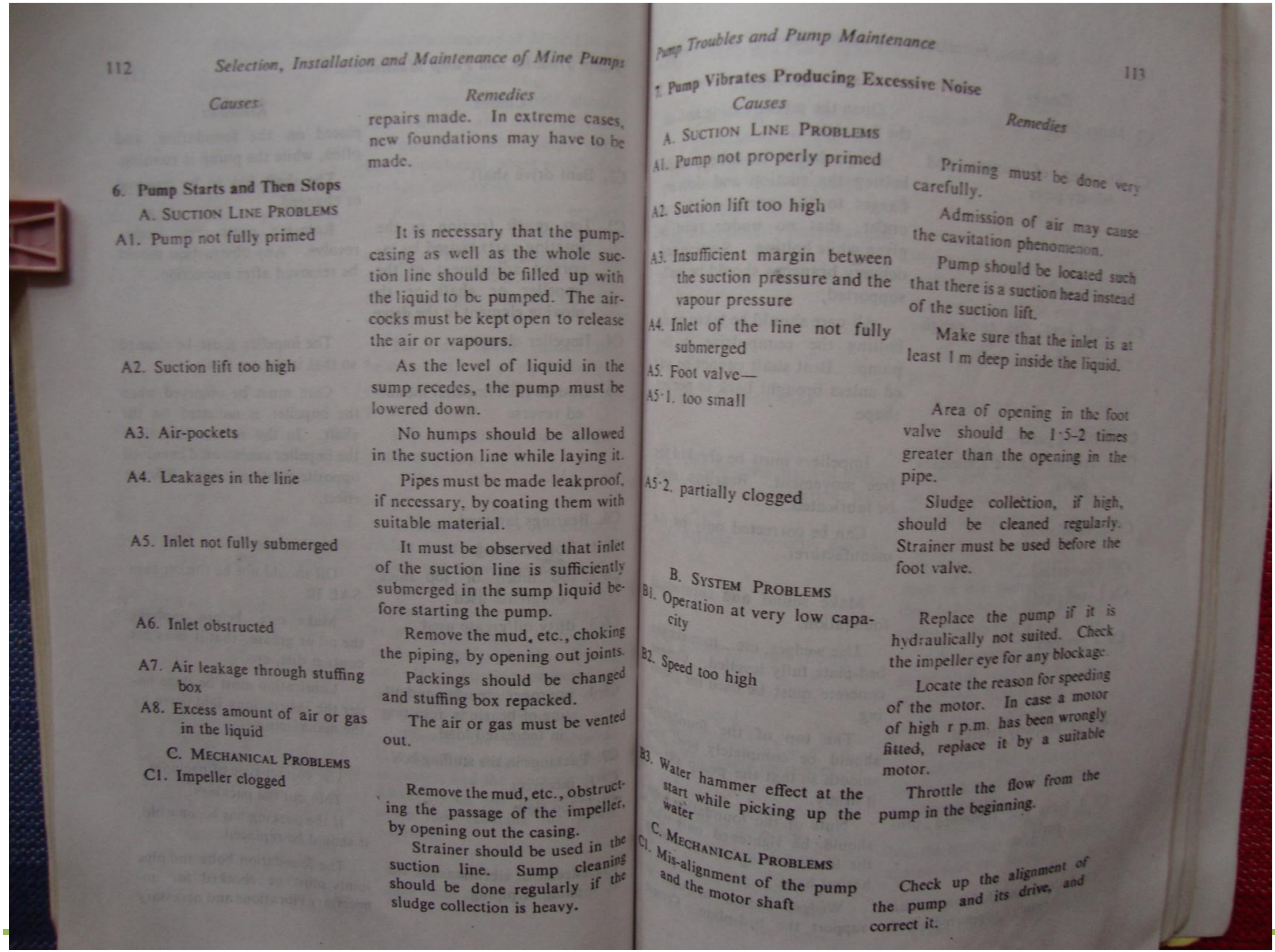
Causes	*Remedies*
	placed on the foundation, and often, while the pump is running.
C2. Bent drive shaft	The shaft has to be repaired or changed.
C3. Too much friction in the rotating parts caused by incorrect adjustment of the impeller or shaft or the moving element in the drive	Rotating parts must freely revolve. Any obstruction should be removed after inspection.
C4. Impeller clogged	The impeller must be cleaned so that it rotates freely.
C5. Double inlet impeller mounted reverse	Care must be observed when the impeller is mounted on the shaft. In the reverse direction, the impeller vanes would be curved opposite creating a much different effect.
C6. Bearings jammed—	
C6·1. worn bearings	Replace them.
C6·2. too much or too thick oil/grease used	Oil should not be thicker than SAE 10.
C6·3. dirty oil/grease used	Make sure, before applying the oil or grease, that it does not contain dirt, etc.
C6·4. improper greasing and oiling of bearings resulting in increased load	Lubrication must be done under the instructions laid down by the manufacturers.
C7. Packings in the stuffing box—	
C7·1. incorrect	Use correct type of packings.
C7·2. too tight	Thin out the packings. If the packing has become old, it should be replaced.
C8. Excessive vibrations of the pump or piping	The foundation bolts and pipe joints must be checked for unnecessary vibrations and necessary



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Causes	*Remedies*
	repairs made. In extreme cases, new foundations may have to be made.

6. Pump Starts and Then Stops

A. SUCTION LINE PROBLEMS

Causes	*Remedies*
A1. Pump not fully primed	It is necessary that the pump-casing as well as the whole suction line should be filled up with the liquid to be pumped. The air-cocks must be kept open to release the air or vapours.
A2. Suction lift too high	As the level of liquid in the sump recedes, the pump must be lowered down.
A3. Air-pockets	No humps should be allowed in the suction line while laying it.
A4. Leakages in the line	Pipes must be made leakproof, if necessary, by coating them with suitable material.
A5. Inlet not fully submerged	It must be observed that inlet of the suction line is sufficiently submerged in the sump liquid before starting the pump.
A6. Inlet obstructed	Remove the mud, etc., choking the piping, by opening out joints.
A7. Air leakage through stuffing box	Packings should be changed and stuffing box repacked.
A8. Excess amount of air or gas in the liquid	The air or gas must be vented out.
C. MECHANICAL PROBLEMS	
C1. Impeller clogged	Remove the mud, etc., obstructing the passage of the impeller, by opening out the casing. Strainer should be used in the suction line. Sump cleaning should be done regularly if the sludge collection is heavy.

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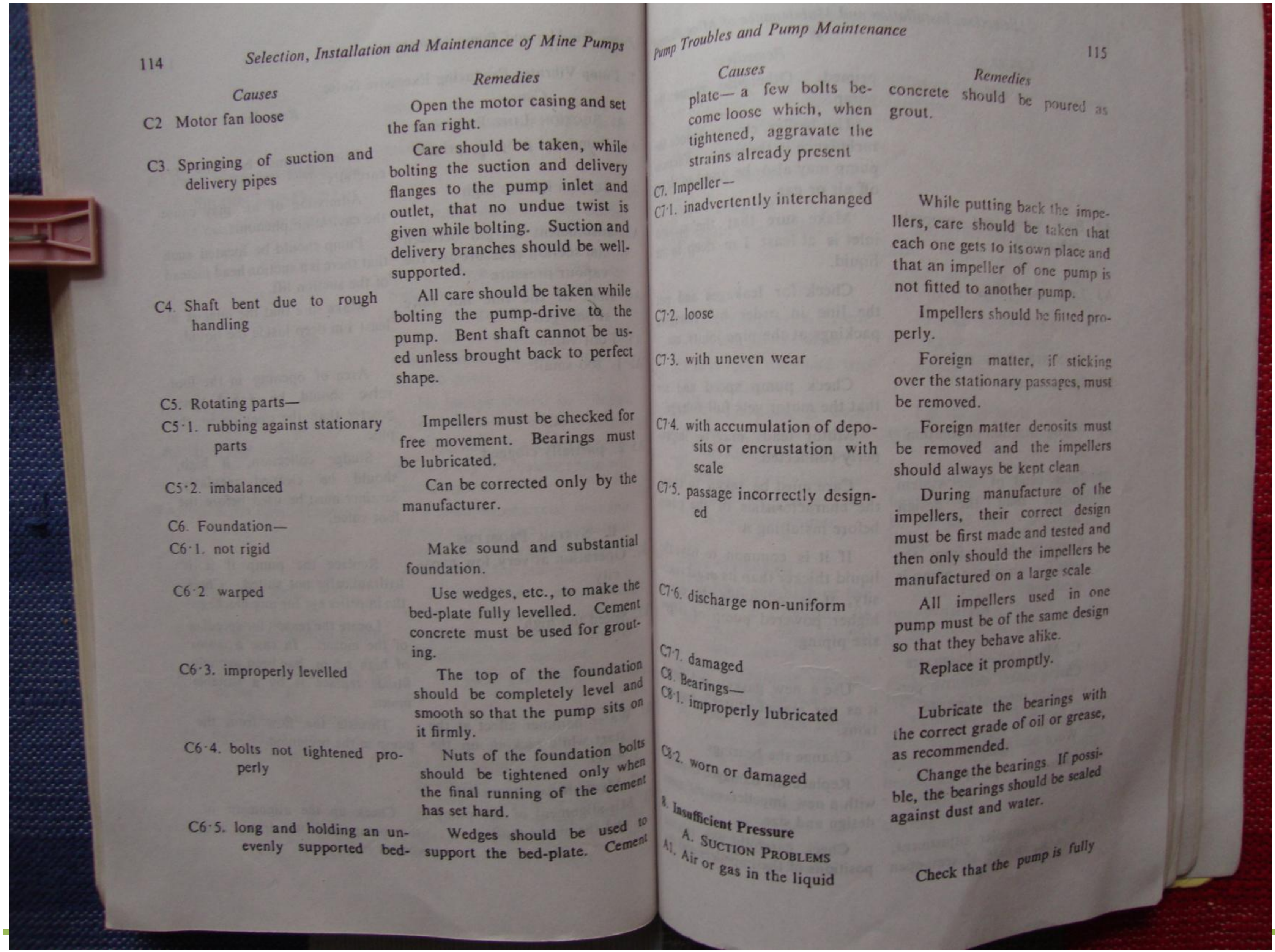
7. Pump Vibrates Producing Excessive Noise

Causes	*Remedies*
A. SUCTION LINE PROBLEMS	
A1. Pump not properly primed	Priming must be done very carefully.
A2. Suction lift too high	Admission of air may cause the cavitation phenomenon.
A3. Insufficient margin between the suction pressure and the vapour pressure	Pump should be located such that there is a suction head instead of the suction lift.
A4. Inlet of the line not fully submerged	Make sure that the inlet is at least 1 m deep inside the liquid.
A5. Foot valve—	
A5·1. too small	Area of opening in the foot valve should be 1·5–2 times greater than the opening in the pipe.
A5·2. partially clogged	Sludge collection, if high, should be cleaned regularly. Strainer must be used before the foot valve.
B. SYSTEM PROBLEMS	
B1. Operation at very low capacity	Replace the pump if it is hydraulically not suited. Check the impeller eye for any blockage.
B2. Speed too high	Locate the reason for speeding of the motor. In case a motor of high r.p.m. has been wrongly fitted, replace it by a suitable motor.
B3. Water hammer effect at the start while picking up the water	Throttle the flow from the pump in the beginning.
C. MECHANICAL PROBLEMS	
C1. Mis-alignment of the pump and the motor shaft	Check up the alignment of the pump and its drive, and correct it.



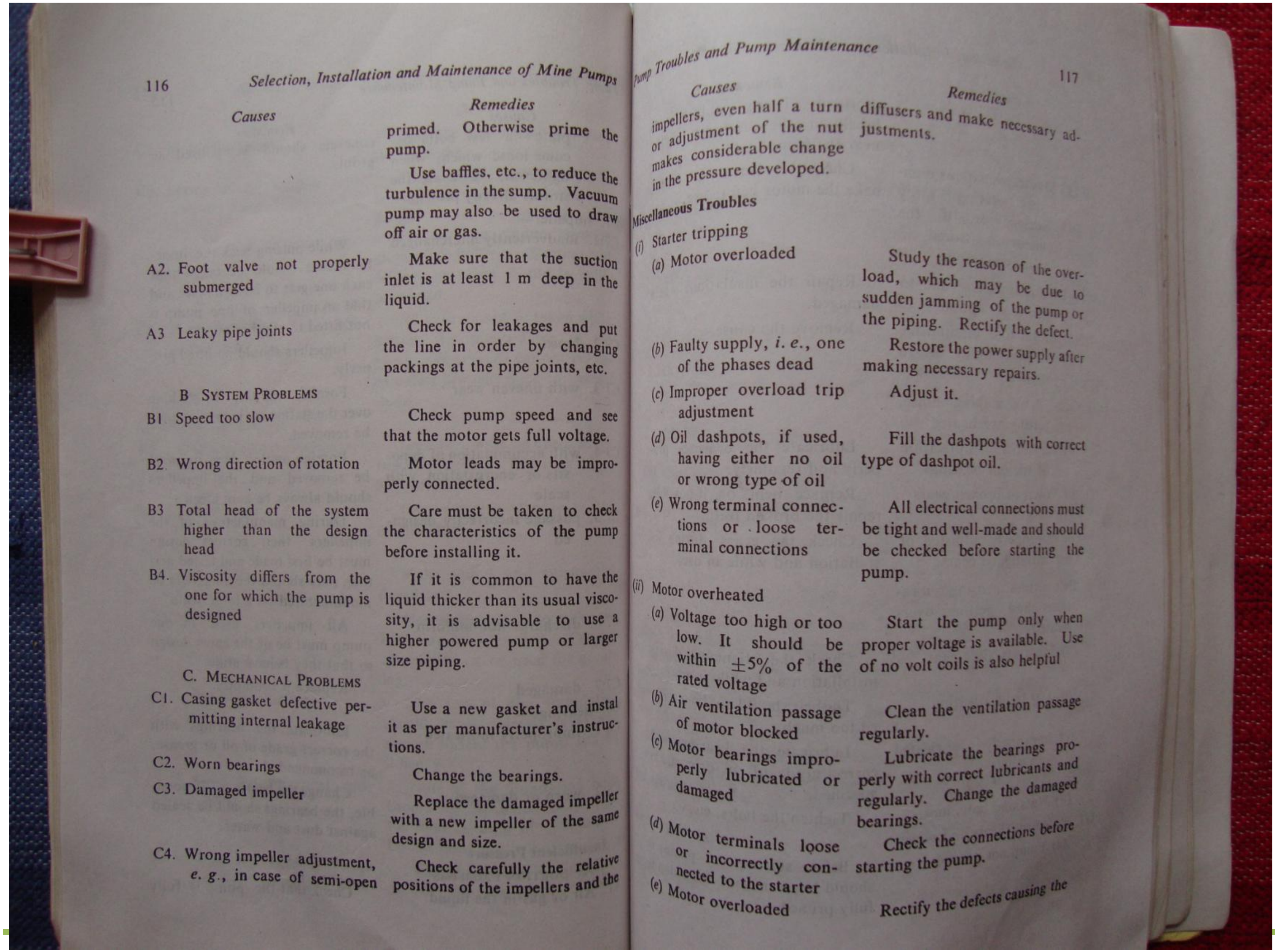
Causes	*Remedies*
C2 Motor fan loose	Open the motor casing and set the fan right.
C3. Springing of suction and delivery pipes	Care should be taken, while bolting the suction and delivery flanges to the pump inlet and outlet, that no undue twist is given while bolting. Suction and delivery branches should be well-supported.
C4. Shaft bent due to rough handling	All care should be taken while bolting the pump-drive to the pump. Bent shaft cannot be used unless brought back to perfect shape.
C5. Rotating parts—	
C5·1. rubbing against stationary parts	Impellers must be checked for free movement. Bearings must be lubricated.
C5·2. imbalanced	Can be corrected only by the manufacturer.
C6. Foundation—	
C6·1. not rigid	Make sound and substantial foundation.
C6·2 warped	Use wedges, etc., to make the bed-plate fully levelled. Cement concrete must be used for grouting.
C6·3. improperly levelled	The top of the foundation should be completely level and smooth so that the pump sits on it firmly.
C6·4. bolts not tightened properly	Nuts of the foundation bolts should be tightened only when the final running of the cement has set hard.
C6·5. long and holding an unevenly supported bed-	Wedges should be used to support the bed-plate. Cement

Causes	*Remedies*
plate— a few bolts become loose which, when tightened, aggravate the strains already present	concrete should be poured as grout.
C7. Impeller—	
C7·1. inadvertently interchanged	While putting back the impellers, care should be taken that each one gets to its own place and that an impeller of one pump is not fitted to another pump.
C7·2. loose	Impellers should be fitted properly.
C7·3. with uneven wear	Foreign matter, if sticking over the stationary passages, must be removed.
C7·4. with accumulation of deposits or encrustation with scale	Foreign matter deposits must be removed and the impellers should always be kept clean
C7·5. passage incorrectly designed	During manufacture of the impellers, their correct design must be first made and tested and then only should the impellers be manufactured on a large scale
C7·6. discharge non-uniform	All impellers used in one pump must be of the same design so that they behave alike.
C7·7. damaged	Replace it promptly.
C8. Bearings—	
C8·1. improperly lubricated	Lubricate the bearings with the correct grade of oil or grease, as recommended.
C8·2. worn or damaged	Change the bearings. If possible, the bearings should be sealed against dust and water.

8. Insufficient Pressure

A. SUCTION PROBLEMS

A1. Air or gas in the liquid	Check that the pump is fully



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Causes	Remedies
	primed. Otherwise prime the pump. Use baffles, etc., to reduce the turbulence in the sump. Vacuum pump may also be used to draw off air or gas.
A2. Foot valve not properly submerged	Make sure that the suction inlet is at least 1 m deep in the liquid.
A3 Leaky pipe joints	Check for leakages and put the line in order by changing packings at the pipe joints, etc.

B SYSTEM PROBLEMS

Causes	Remedies
B1 Speed too slow	Check pump speed and see that the motor gets full voltage.
B2 Wrong direction of rotation	Motor leads may be improperly connected.
B3 Total head of the system higher than the design head	Care must be taken to check the characteristics of the pump before installing it.
B4. Viscosity differs from the one for which the pump is designed	If it is common to have the liquid thicker than its usual viscosity, it is advisable to use a higher powered pump or larger size piping.

C. MECHANICAL PROBLEMS

Causes	Remedies
C1. Casing gasket defective permitting internal leakage	Use a new gasket and instal it as per manufacturer's instructions.
C2. Worn bearings	Change the bearings.
C3. Damaged impeller	Replace the damaged impeller with a new impeller of the same design and size.
C4. Wrong impeller adjustment, e. g., in case of semi-open	Check carefully the relative positions of the impellers and the

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Causes	Remedies
impellers, even half a turn or adjustment of the nut makes considerable change in the pressure developed.	diffusers and make necessary adjustments.

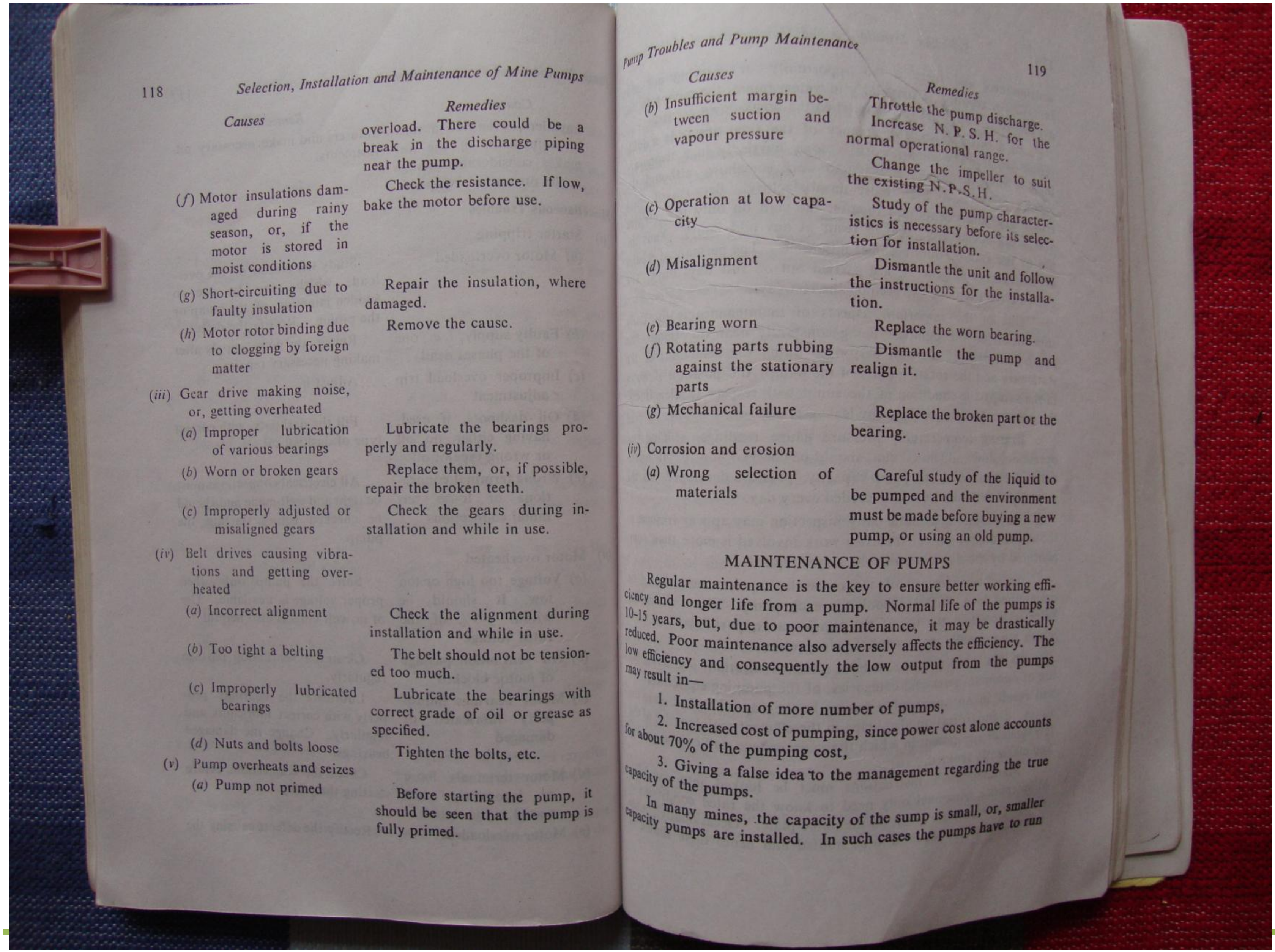
Miscellaneous Troubles

(i) Starter tripping

Causes	Remedies
(a) Motor overloaded	Study the reason of the overload, which may be due to sudden jamming of the pump or the piping. Rectify the defect.
(b) Faulty supply, i. e., one of the phases dead	Restore the power supply after making necessary repairs.
(c) Improper overload trip adjustment	Adjust it.
(d) Oil dashpots, if used, having either no oil or wrong type of oil	Fill the dashpots with correct type of dashpot oil.
(e) Wrong terminal connections or loose terminal connections	All electrical connections must be tight and well-made and should be checked before starting the pump.

(ii) Motor overheated

Causes	Remedies
(a) Voltage too high or too low. It should be within ±5% of the rated voltage	Start the pump only when proper voltage is available. Use of no volt coils is also helpful
(b) Air ventilation passage of motor blocked	Clean the ventilation passage regularly.
(c) Motor bearings improperly lubricated or damaged	Lubricate the bearings properly with correct lubricants and regularly. Change the damaged bearings.
(d) Motor terminals loose or incorrectly connected to the starter	Check the connections before starting the pump.
(e) Motor overloaded	Rectify the defects causing the



Causes	Remedies
	overload. There could be a break in the discharge piping near the pump.
(*f*) Motor insulations damaged during rainy season, or, if the motor is stored in moist conditions	Check the resistance. If low, bake the motor before use.
(*g*) Short-circuiting due to faulty insulation	Repair the insulation, where damaged.
(*h*) Motor rotor binding due to clogging by foreign matter	Remove the cause.
(*iii*) Gear drive making noise, or, getting overheated	
(*a*) Improper lubrication of various bearings	Lubricate the bearings properly and regularly.
(*b*) Worn or broken gears	Replace them, or, if possible, repair the broken teeth.
(*c*) Improperly adjusted or misaligned gears	Check the gears during installation and while in use.
(*iv*) Belt drives causing vibrations and getting overheated	
(*a*) Incorrect alignment	Check the alignment during installation and while in use.
(*b*) Too tight a belting	The belt should not be tensioned too much.
(*c*) Improperly lubricated bearings	Lubricate the bearings with correct grade of oil or grease as specified.
(*d*) Nuts and bolts loose	Tighten the bolts, etc.
(*v*) Pump overheats and seizes	
(*a*) Pump not primed	Before starting the pump, it should be seen that the pump is fully primed.

Causes	Remedies
(*b*) Insufficient margin between suction and vapour pressure	Throttle the pump discharge. Increase N. P. S. H. for the normal operational range. Change the impeller to suit the existing N.P.S.H.
(*c*) Operation at low capacity	Study of the pump characteristics is necessary before its selection for installation.
(*d*) Misalignment	Dismantle the unit and follow the instructions for the installation.
(*e*) Bearing worn	Replace the worn bearing.
(*f*) Rotating parts rubbing against the stationary parts	Dismantle the pump and realign it.
(*g*) Mechanical failure	Replace the broken part or the bearing.
(*iv*) Corrosion and erosion	
(*a*) Wrong selection of materials	Careful study of the liquid to be pumped and the environment must be made before buying a new pump, or using an old pump.

MAINTENANCE OF PUMPS

Regular maintenance is the key to ensure better working efficiency and longer life from a pump. Normal life of the pumps is 10-15 years, but, due to poor maintenance, it may be drastically reduced. Poor maintenance also adversely affects the efficiency. The low efficiency and consequently the low output from the pumps may result in—

1. Installation of more number of pumps,
2. Increased cost of pumping, since power cost alone accounts for about 70% of the pumping cost,
3. Giving a false idea to the management regarding the true capacity of the pumps.

In many mines, the capacity of the sump is small, or, smaller capacity pumps are installed. In such cases the pumps have to run

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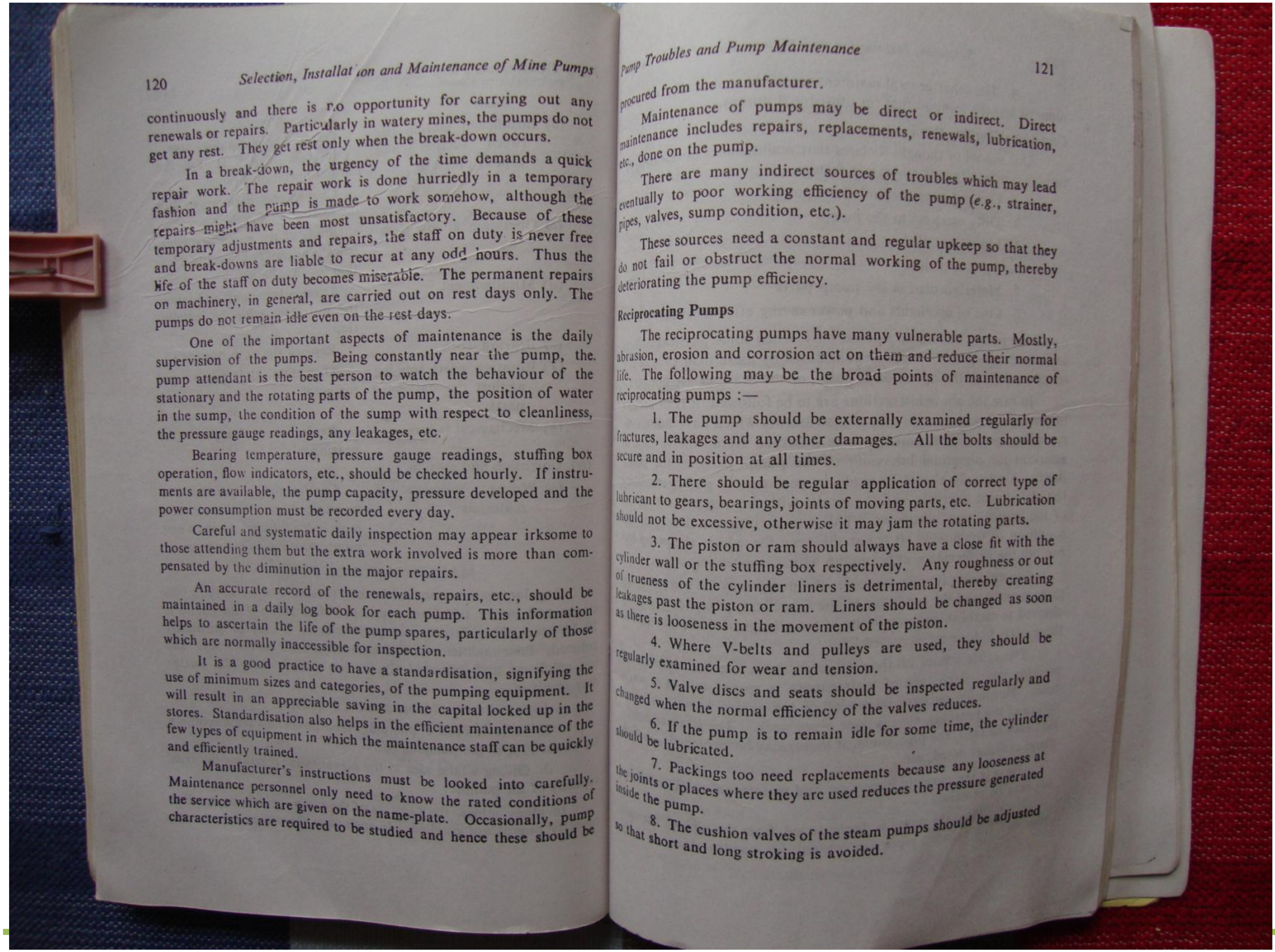

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continuously and there is no opportunity for carrying out any renewals or repairs. Particularly in watery mines, the pumps do not get any rest. They get rest only when the break-down occurs.

In a break-down, the urgency of the time demands a quick repair work. The repair work is done hurriedly in a temporary fashion and the pump is made to work somehow, although the repairs might have been most unsatisfactory. Because of these temporary adjustments and repairs, the staff on duty is never free and break-downs are liable to recur at any odd hours. Thus the life of the staff on duty becomes miserable. The permanent repairs on machinery, in general, are carried out on rest days only. The pumps do not remain idle even on the rest days.

One of the important aspects of maintenance is the daily supervision of the pumps. Being constantly near the pump, the pump attendant is the best person to watch the behaviour of the stationary and the rotating parts of the pump, the position of water in the sump, the condition of the sump with respect to cleanliness, the pressure gauge readings, any leakages, etc.

Bearing temperature, pressure gauge readings, stuffing box operation, flow indicators, etc., should be checked hourly. If instruments are available, the pump capacity, pressure developed and the power consumption must be recorded every day.

Careful and systematic daily inspection may appear irksome to those attending them but the extra work involved is more than compensated by the diminution in the major repairs.

An accurate record of the renewals, repairs, etc., should be maintained in a daily log book for each pump. This information helps to ascertain the life of the pump spares, particularly of those which are normally inaccessible for inspection.

It is a good practice to have a standardisation, signifying the use of minimum sizes and categories, of the pumping equipment. It will result in an appreciable saving in the capital locked up in the stores. Standardisation also helps in the efficient maintenance of the few types of equipment in which the maintenance staff can be quickly and efficiently trained.

Manufacturer's instructions must be looked into carefully. Maintenance personnel only need to know the rated conditions of the service which are given on the name-plate. Occasionally, pump characteristics are required to be studied and hence these should be

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procured from the manufacturer.

Maintenance of pumps may be direct or indirect. Direct maintenance includes repairs, replacements, renewals, lubrication, etc., done on the pump.

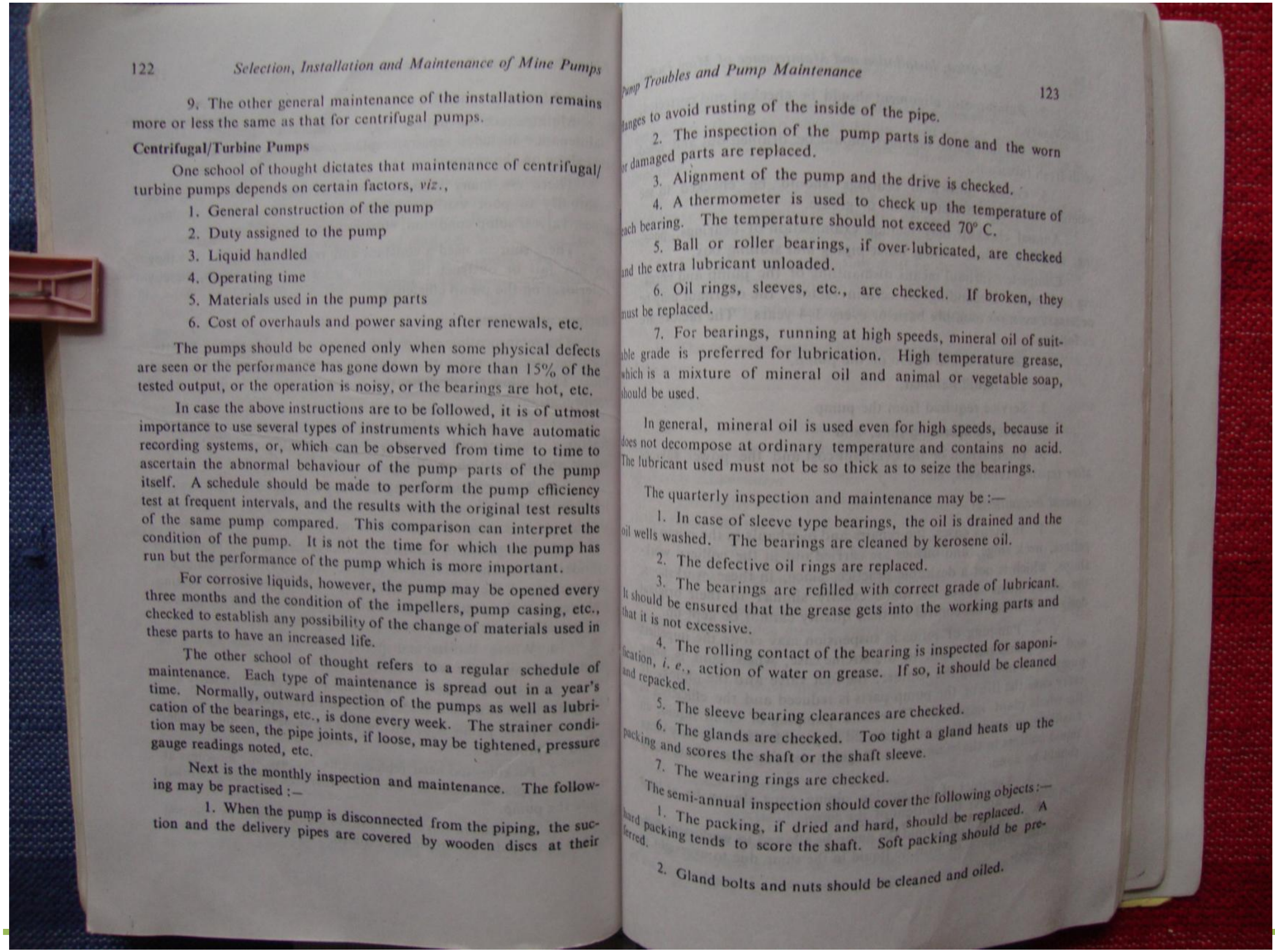
There are many indirect sources of troubles which may lead eventually to poor working efficiency of the pump (*e.g.*, strainer, pipes, valves, sump condition, etc.).

These sources need a constant and regular upkeep so that they do not fail or obstruct the normal working of the pump, thereby deteriorating the pump efficiency.

Reciprocating Pumps

The reciprocating pumps have many vulnerable parts. Mostly, abrasion, erosion and corrosion act on them and reduce their normal life. The following may be the broad points of maintenance of reciprocating pumps :—

1. The pump should be externally examined regularly for fractures, leakages and any other damages. All the bolts should be secure and in position at all times.
2. There should be regular application of correct type of lubricant to gears, bearings, joints of moving parts, etc. Lubrication should not be excessive, otherwise it may jam the rotating parts.
3. The piston or ram should always have a close fit with the cylinder wall or the stuffing box respectively. Any roughness or out of trueness of the cylinder liners is detrimental, thereby creating leakages past the piston or ram. Liners should be changed as soon as there is looseness in the movement of the piston.
4. Where V-belts and pulleys are used, they should be regularly examined for wear and tension.
5. Valve discs and seats should be inspected regularly and changed when the normal efficiency of the valves reduces.
6. If the pump is to remain idle for some time, the cylinder should be lubricated.
7. Packings too need replacements because any looseness at the joints or places where they are used reduces the pressure generated inside the pump.
8. The cushion valves of the steam pumps should be adjusted so that short and long stroking is avoided.



9. The other general maintenance of the installation remains more or less the same as that for centrifugal pumps.

Centrifugal/Turbine Pumps

One school of thought dictates that maintenance of centrifugal/turbine pumps depends on certain factors, *viz.*,

1. General construction of the pump
2. Duty assigned to the pump
3. Liquid handled
4. Operating time
5. Materials used in the pump parts
6. Cost of overhauls and power saving after renewals, etc.

The pumps should be opened only when some physical defects are seen or the performance has gone down by more than 15% of the tested output, or the operation is noisy, or the bearings are hot, etc.

In case the above instructions are to be followed, it is of utmost importance to use several types of instruments which have automatic recording systems, or, which can be observed from time to time to ascertain the abnormal behaviour of the pump parts of the pump itself. A schedule should be made to perform the pump efficiency test at frequent intervals, and the results with the original test results of the same pump compared. This comparison can interpret the condition of the pump. It is not the time for which the pump has run but the performance of the pump which is more important.

For corrosive liquids, however, the pump may be opened every three months and the condition of the impellers, pump casing, etc., checked to establish any possibility of the change of materials used in these parts to have an increased life.

The other school of thought refers to a regular schedule of maintenance. Each type of maintenance is spread out in a year's time. Normally, outward inspection of the pumps as well as lubrication of the bearings, etc., is done every week. The strainer condition may be seen, the pipe joints, if loose, may be tightened, pressure gauge readings noted, etc.

Next is the monthly inspection and maintenance. The following may be practised :—

1. When the pump is disconnected from the piping, the suction and the delivery pipes are covered by wooden discs at their

flanges to avoid rusting of the inside of the pipe.

2. The inspection of the pump parts is done and the worn or damaged parts are replaced.

3. Alignment of the pump and the drive is checked.

4. A thermometer is used to check up the temperature of each bearing. The temperature should not exceed 70° C.

5. Ball or roller bearings, if over-lubricated, are checked and the extra lubricant unloaded.

6. Oil rings, sleeves, etc., are checked. If broken, they must be replaced.

7. For bearings, running at high speeds, mineral oil of suitable grade is preferred for lubrication. High temperature grease, which is a mixture of mineral oil and animal or vegetable soap, should be used.

In general, mineral oil is used even for high speeds, because it does not decompose at ordinary temperature and contains no acid. The lubricant used must not be so thick as to seize the bearings.

The quarterly inspection and maintenance may be :—

1. In case of sleeve type bearings, the oil is drained and the oil wells washed. The bearings are cleaned by kerosene oil.

2. The defective oil rings are replaced.

3. The bearings are refilled with correct grade of lubricant. It should be ensured that the grease gets into the working parts and that it is not excessive.

4. The rolling contact of the bearing is inspected for saponification, *i. e.*, action of water on grease. If so, it should be cleaned and repacked.

5. The sleeve bearing clearances are checked.

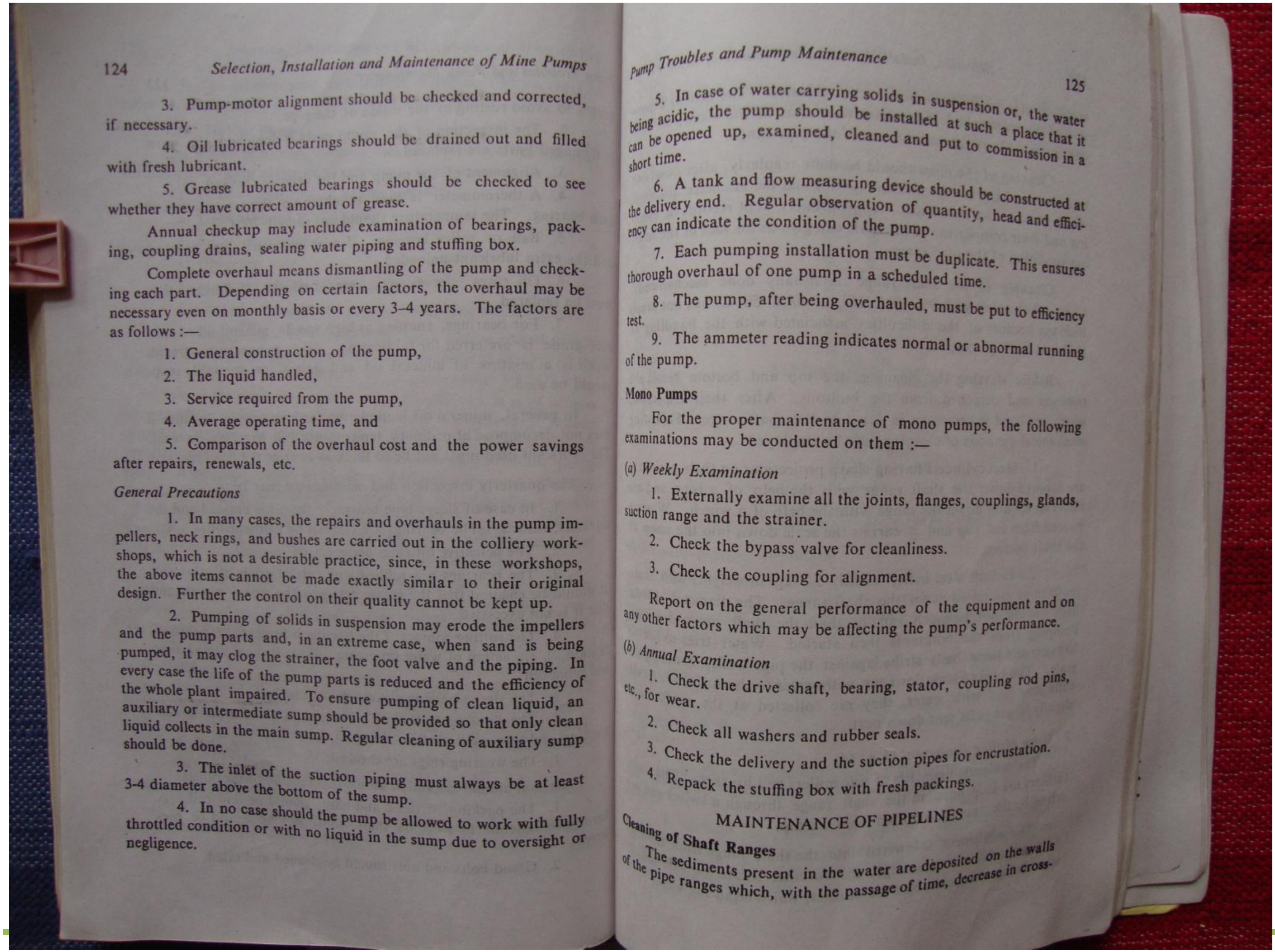
6. The glands are checked. Too tight a gland heats up the packing and scores the shaft or the shaft sleeve.

7. The wearing rings are checked.

The semi-annual inspection should cover the following objects :—

1. The packing, if dried and hard, should be replaced. A hard packing tends to score the shaft. Soft packing should be preferred.

2. Gland bolts and nuts should be cleaned and oiled.



3. Pump-motor alignment should be checked and corrected, if necessary.

4. Oil lubricated bearings should be drained out and filled with fresh lubricant.

5. Grease lubricated bearings should be checked to see whether they have correct amount of grease.

Annual checkup may include examination of bearings, packing, coupling drains, sealing water piping and stuffing box.

Complete overhaul means dismantling of the pump and checking each part. Depending on certain factors, the overhaul may be necessary even on monthly basis or every 3–4 years. The factors are as follows :—

1. General construction of the pump,
2. The liquid handled,
3. Service required from the pump,
4. Average operating time, and
5. Comparison of the overhaul cost and the power savings after repairs, renewals, etc.

General Precautions

1. In many cases, the repairs and overhauls in the pump impellers, neck rings, and bushes are carried out in the colliery workshops, which is not a desirable practice, since, in these workshops, the above items cannot be made exactly similar to their original design. Further the control on their quality cannot be kept up.

2. Pumping of solids in suspension may erode the impellers and the pump parts and, in an extreme case, when sand is being pumped, it may clog the strainer, the foot valve and the piping. In every case the life of the pump parts is reduced and the efficiency of the whole plant impaired. To ensure pumping of clean liquid, an auxiliary or intermediate sump should be provided so that only clean liquid collects in the main sump. Regular cleaning of auxiliary sump should be done.

3. The inlet of the suction piping must always be at least 3-4 diameter above the bottom of the sump.

4. In no case should the pump be allowed to work with fully throttled condition or with no liquid in the sump due to oversight or negligence.

5. In case of water carrying solids in suspension or, the water being acidic, the pump should be installed at such a place that it can be opened up, examined, cleaned and put to commission in a short time.

6. A tank and flow measuring device should be constructed at the delivery end. Regular observation of quantity, head and efficiency can indicate the condition of the pump.

7. Each pumping installation must be duplicate. This ensures thorough overhaul of one pump in a scheduled time.

8. The pump, after being overhauled, must be put to efficiency test.

9. The ammeter reading indicates normal or abnormal running of the pump.

Mono Pumps

For the proper maintenance of mono pumps, the following examinations may be conducted on them :—

(*a*) *Weekly Examination*

1. Externally examine all the joints, flanges, couplings, glands, suction range and the strainer.
2. Check the bypass valve for cleanliness.
3. Check the coupling for alignment.

Report on the general performance of the equipment and on any other factors which may be affecting the pump's performance.

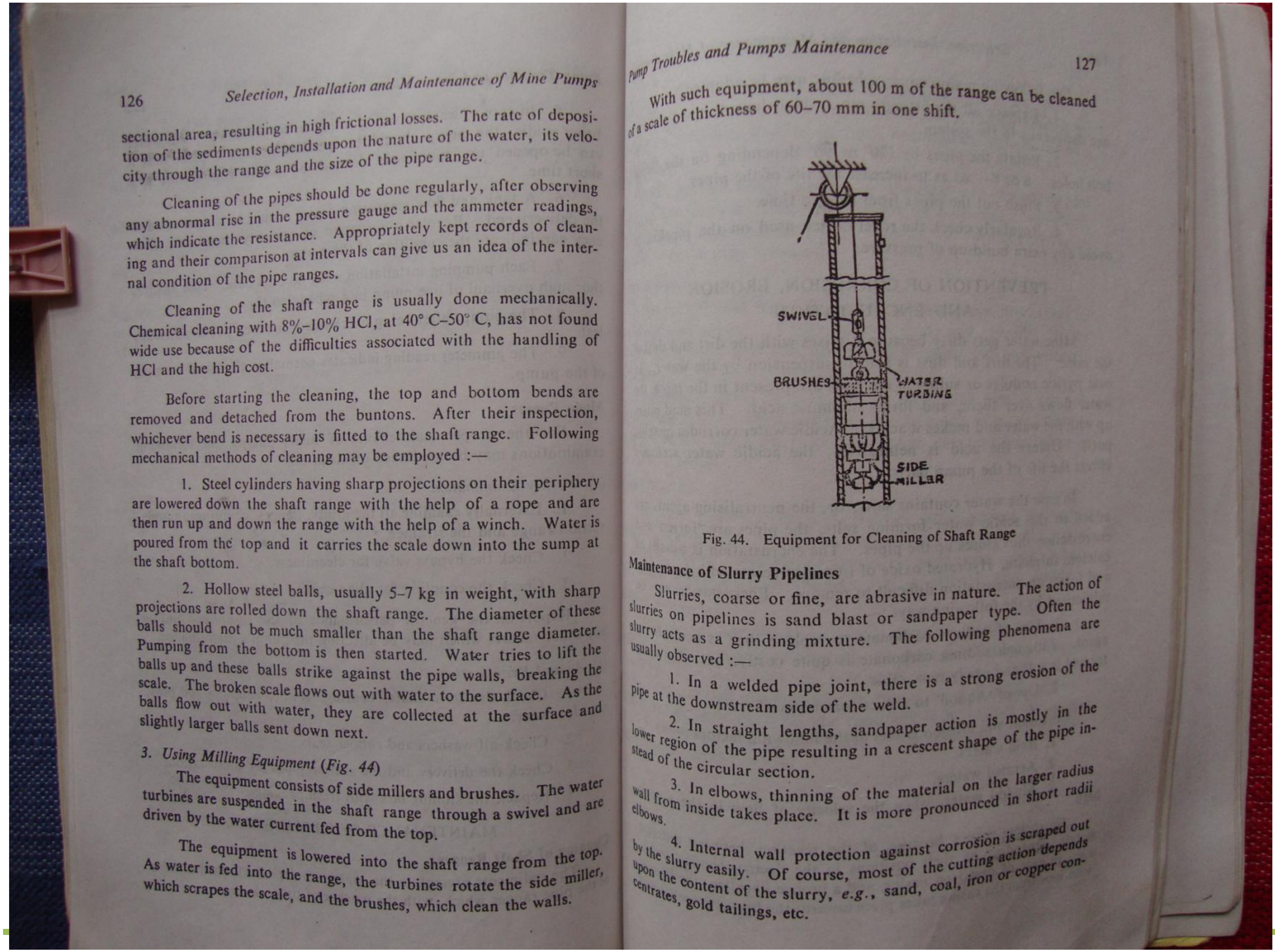
(*b*) *Annual Examination*

1. Check the drive shaft, bearing, stator, coupling rod pins, etc., for wear.
2. Check all washers and rubber seals.
3. Check the delivery and the suction pipes for encrustation.
4. Repack the stuffing box with fresh packings.

MAINTENANCE OF PIPELINES

Cleaning of Shaft Ranges

The sediments present in the water are deposited on the walls of the pipe ranges which, with the passage of time, decrease in cross-


SWIVEL
BRUSHES
WATER TURBINE
SIDE MILLER

sectional area, resulting in high frictional losses. The rate of deposition of the sediments depends upon the nature of the water, its velocity through the range and the size of the pipe range.

Cleaning of the pipes should be done regularly, after observing any abnormal rise in the pressure gauge and the ammeter readings, which indicate the resistance. Appropriately kept records of cleaning and their comparison at intervals can give us an idea of the internal condition of the pipe ranges.

Cleaning of the shaft range is usually done mechanically. Chemical cleaning with 8%–10% HCl, at 40° C–50° C, has not found wide use because of the difficulties associated with the handling of HCl and the high cost.

Before starting the cleaning, the top and bottom bends are removed and detached from the buntons. After their inspection, whichever bend is necessary is fitted to the shaft range. Following mechanical methods of cleaning may be employed :—

1. Steel cylinders having sharp projections on their periphery are lowered down the shaft range with the help of a rope and are then run up and down the range with the help of a winch. Water is poured from the top and it carries the scale down into the sump at the shaft bottom.

2. Hollow steel balls, usually 5–7 kg in weight, with sharp projections are rolled down the shaft range. The diameter of these balls should not be much smaller than the shaft range diameter. Pumping from the bottom is then started. Water tries to lift the balls up and these balls strike against the pipe walls, breaking the scale. The broken scale flows out with water to the surface. As the balls flow out with water, they are collected at the surface and slightly larger balls sent down next.

3. *Using Milling Equipment (Fig. 44)*

The equipment consists of side millers and brushes. The water turbines are suspended in the shaft range through a swivel and are driven by the water current fed from the top.

The equipment is lowered into the shaft range from the top. As water is fed into the range, the turbines rotate the side miller, which scrapes the scale, and the brushes, which clean the walls.

With such equipment, about 100 m of the range can be cleaned of a scale of thickness of 60–70 mm in one shift.

Fig. 44. Equipment for Cleaning of Shaft Range

Maintenance of Slurry Pipelines

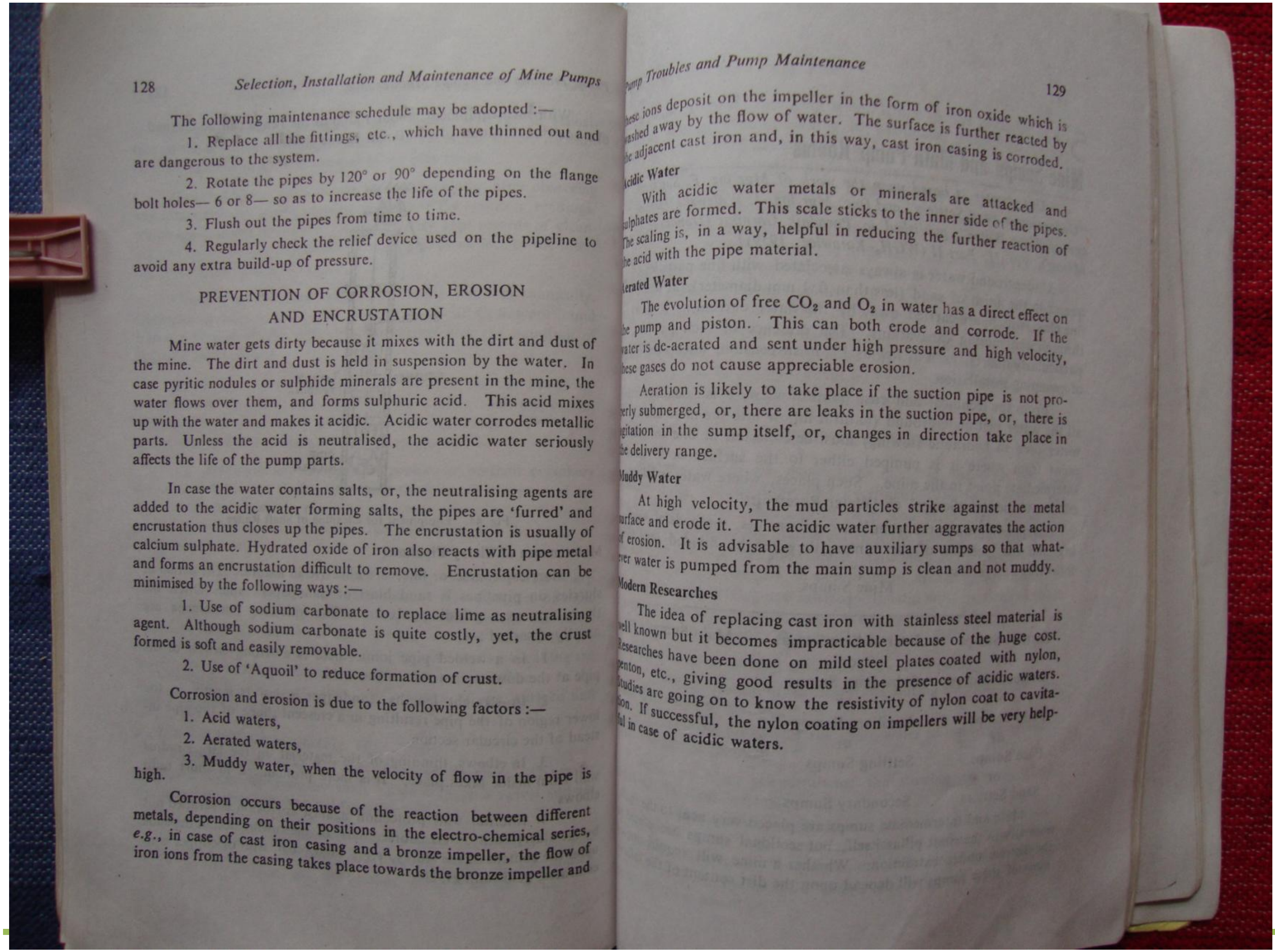
Slurries, coarse or fine, are abrasive in nature. The action of slurries on pipelines is sand blast or sandpaper type. Often the slurry acts as a grinding mixture. The following phenomena are usually observed :—

1. In a welded pipe joint, there is a strong erosion of the pipe at the downstream side of the weld.

2. In straight lengths, sandpaper action is mostly in the lower region of the pipe resulting in a crescent shape of the pipe instead of the circular section.

3. In elbows, thinning of the material on the larger radius wall from inside takes place. It is more pronounced in short radii elbows.

4. Internal wall protection against corrosion is scraped out by the slurry easily. Of course, most of the cutting action depends upon the content of the slurry, *e.g.*, sand, coal, iron or copper concentrates, gold tailings, etc.



The following maintenance schedule may be adopted :—

1. Replace all the fittings, etc., which have thinned out and are dangerous to the system.

2. Rotate the pipes by 120° or 90° depending on the flange bolt holes— 6 or 8— so as to increase the life of the pipes.

3. Flush out the pipes from time to time.

4. Regularly check the relief device used on the pipeline to avoid any extra build-up of pressure.

PREVENTION OF CORROSION, EROSION AND ENCRUSTATION

Mine water gets dirty because it mixes with the dirt and dust of the mine. The dirt and dust is held in suspension by the water. In case pyritic nodules or sulphide minerals are present in the mine, the water flows over them, and forms sulphuric acid. This acid mixes up with the water and makes it acidic. Acidic water corrodes metallic parts. Unless the acid is neutralised, the acidic water seriously affects the life of the pump parts.

In case the water contains salts, or, the neutralising agents are added to the acidic water forming salts, the pipes are 'furred' and encrustation thus closes up the pipes. The encrustation is usually of calcium sulphate. Hydrated oxide of iron also reacts with pipe metal and forms an encrustation difficult to remove. Encrustation can be minimised by the following ways :—

1. Use of sodium carbonate to replace lime as neutralising agent. Although sodium carbonate is quite costly, yet, the crust formed is soft and easily removable.

2. Use of 'Aquoil' to reduce formation of crust.

Corrosion and erosion is due to the following factors :—

1. Acid waters,
2. Aerated waters,
3. Muddy water, when the velocity of flow in the pipe is high.

Corrosion occurs because of the reaction between different metals, depending on their positions in the electro-chemical series, *e.g.*, in case of cast iron casing and a bronze impeller, the flow of iron ions from the casing takes place towards the bronze impeller and

hese ions deposit on the impeller in the form of iron oxide which is ashed away by the flow of water. The surface is further reacted by he adjacent cast iron and, in this way, cast iron casing is corroded.

cidic Water

With acidic water metals or minerals are attacked and ulphates are formed. This scale sticks to the inner side of the pipes. The scaling is, in a way, helpful in reducing the further reaction of he acid with the pipe material.

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The evolution of free CO_2 and O_2 in water has a direct effect on he pump and piston. This can both erode and corrode. If the ater is de-aerated and sent under high pressure and high velocity, hese gases do not cause appreciable erosion.

Aeration is likely to take place if the suction pipe is not properly submerged, or, there are leaks in the suction pipe, or, there is gitation in the sump itself, or, changes in direction take place in he delivery range.

uddy Water

At high velocity, the mud particles strike against the metal urface and erode it. The acidic water further aggravates the action f erosion. It is advisable to have auxiliary sumps so that whatever water is pumped from the main sump is clean and not muddy.

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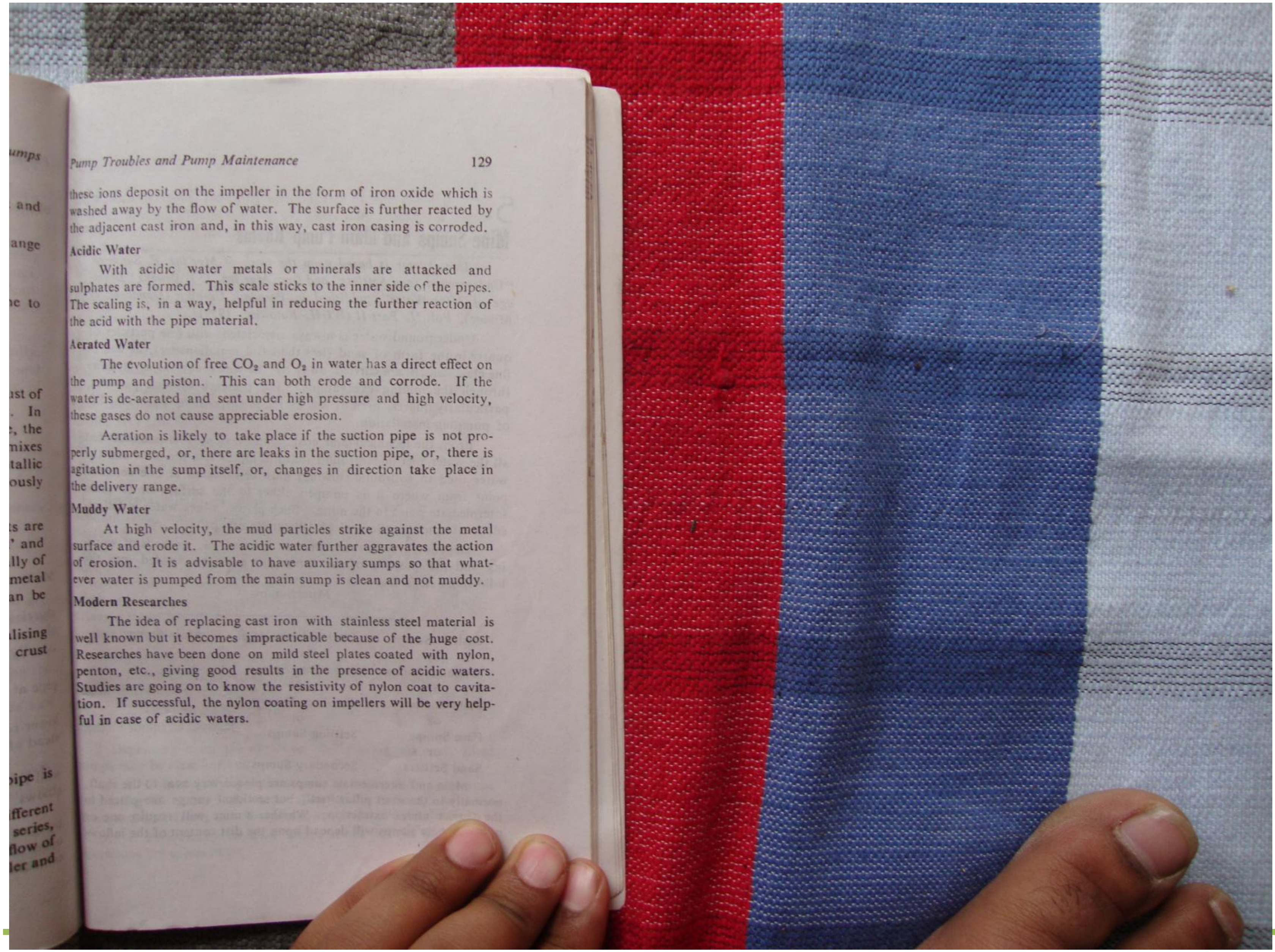
The idea of replacing cast iron with stainless steel material is ell known but it becomes impracticable because of the huge cost. esearches have been done on mild steel plates coated with nylon, enton, etc., giving good results in the presence of acidic waters. tudies are going on to know the resistivity of nylon coat to cavitaon. If successful, the nylon coating on impellers will be very helpul in case of acidic waters.



these ions deposit on the impeller in the form of iron oxide which is washed away by the flow of water. The surface is further reacted by the adjacent cast iron and, in this way, cast iron casing is corroded.

Acidic Water

With acidic water metals or minerals are attacked and sulphates are formed. This scale sticks to the inner side of the pipes. The scaling is, in a way, helpful in reducing the further reaction of the acid with the pipe material.

Aerated Water

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Modern Researches

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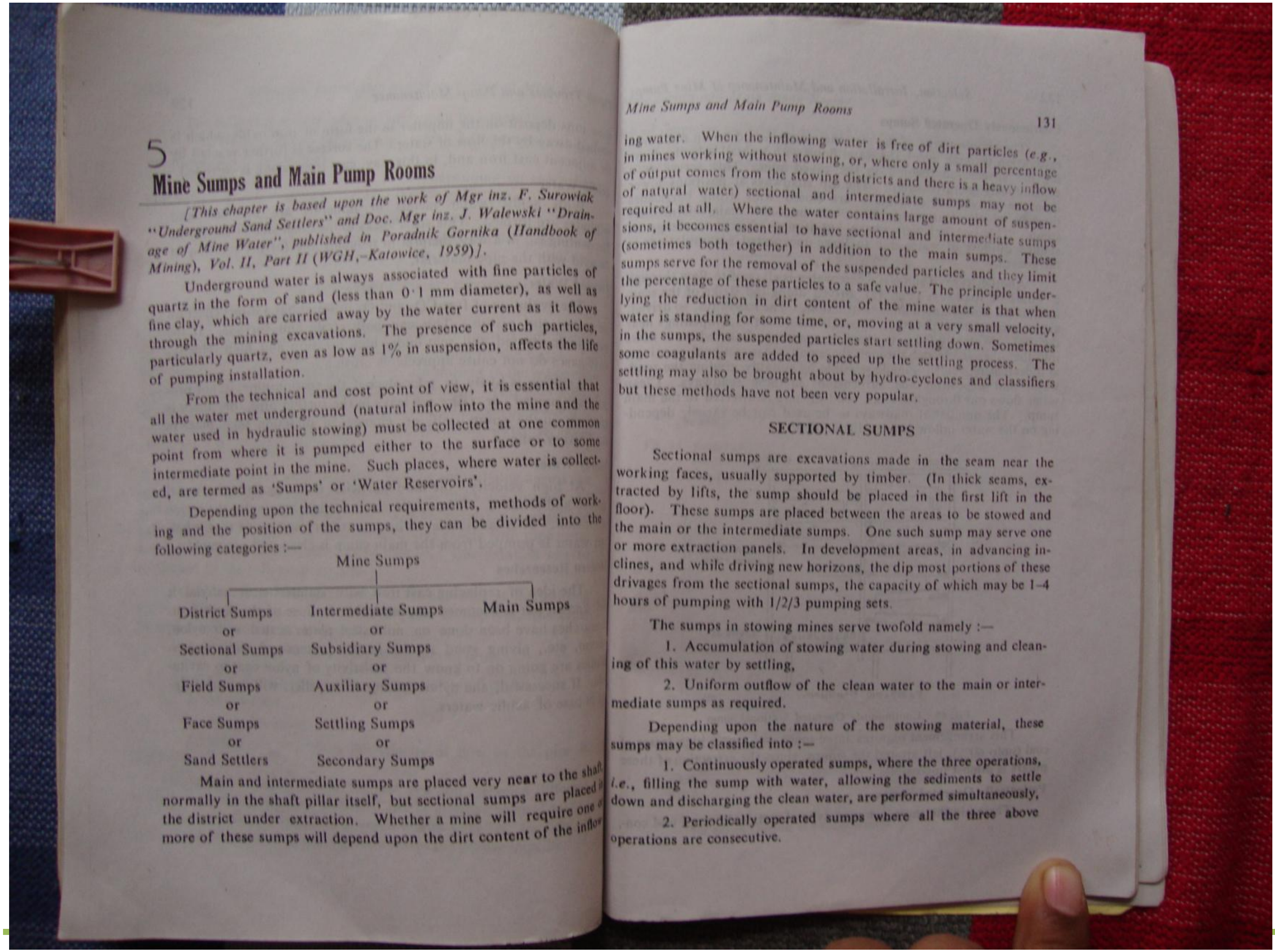


5

Mine Sumps and Main Pump Rooms

[This chapter is based upon the work of Mgr inz. F. Surowiak "Underground Sand Settlers" and Doc. Mgr inz. J. Walewski "Drainage of Mine Water", published in Poradnik Gornika (Handbook of Mining), Vol. II, Part II (WGH,-Katowice, 1959)].

Underground water is always associated with fine particles of quartz in the form of sand (less than 0·1 mm diameter), as well as fine clay, which are carried away by the water current as it flows through the mining excavations. The presence of such particles, particularly quartz, even as low as 1% in suspension, affects the life of pumping installation.

From the technical and cost point of view, it is essential that all the water met underground (natural inflow into the mine and the water used in hydraulic stowing) must be collected at one common point from where it is pumped either to the surface or to some intermediate point in the mine. Such places, where water is collected, are termed as 'Sumps' or 'Water Reservoirs'.

Depending upon the technical requirements, methods of working and the position of the sumps, they can be divided into the following categories :—

Mine Sumps

District Sumps	Intermediate Sumps	Main Sumps
or	or	
Sectional Sumps	Subsidiary Sumps	
or	or	
Field Sumps	Auxiliary Sumps	
or	or	
Face Sumps	Settling Sumps	
or	or	
Sand Settlers	Secondary Sumps	

Main and intermediate sumps are placed very near to the shaft, normally in the shaft pillar itself, but sectional sumps are placed i the district under extraction. Whether a mine will require one o more of these sumps will depend upon the dirt content of the inflowing water. When the inflowing water is free of dirt particles (*e.g.*, in mines working without stowing, or, where only a small percentage of output comes from the stowing districts and there is a heavy inflow of natural water) sectional and intermediate sumps may not be required at all. Where the water contains large amount of suspensions, it becomes essential to have sectional and intermediate sumps (sometimes both together) in addition to the main sumps. These sumps serve for the removal of the suspended particles and they limit the percentage of these particles to a safe value. The principle underlying the reduction in dirt content of the mine water is that when water is standing for some time, or, moving at a very small velocity, in the sumps, the suspended particles start settling down. Sometimes some coagulants are added to speed up the settling process. The settling may also be brought about by hydro-cyclones and classifiers but these methods have not been very popular.

SECTIONAL SUMPS

Sectional sumps are excavations made in the seam near the working faces, usually supported by timber. (In thick seams, extracted by lifts, the sump should be placed in the first lift in the floor). These sumps are placed between the areas to be stowed and the main or the intermediate sumps. One such sump may serve one or more extraction panels. In development areas, in advancing inclines, and while driving new horizons, the dip most portions of these drivages from the sectional sumps, the capacity of which may be 1-4 hours of pumping with 1/2/3 pumping sets.

The sumps in stowing mines serve twofold namely :—

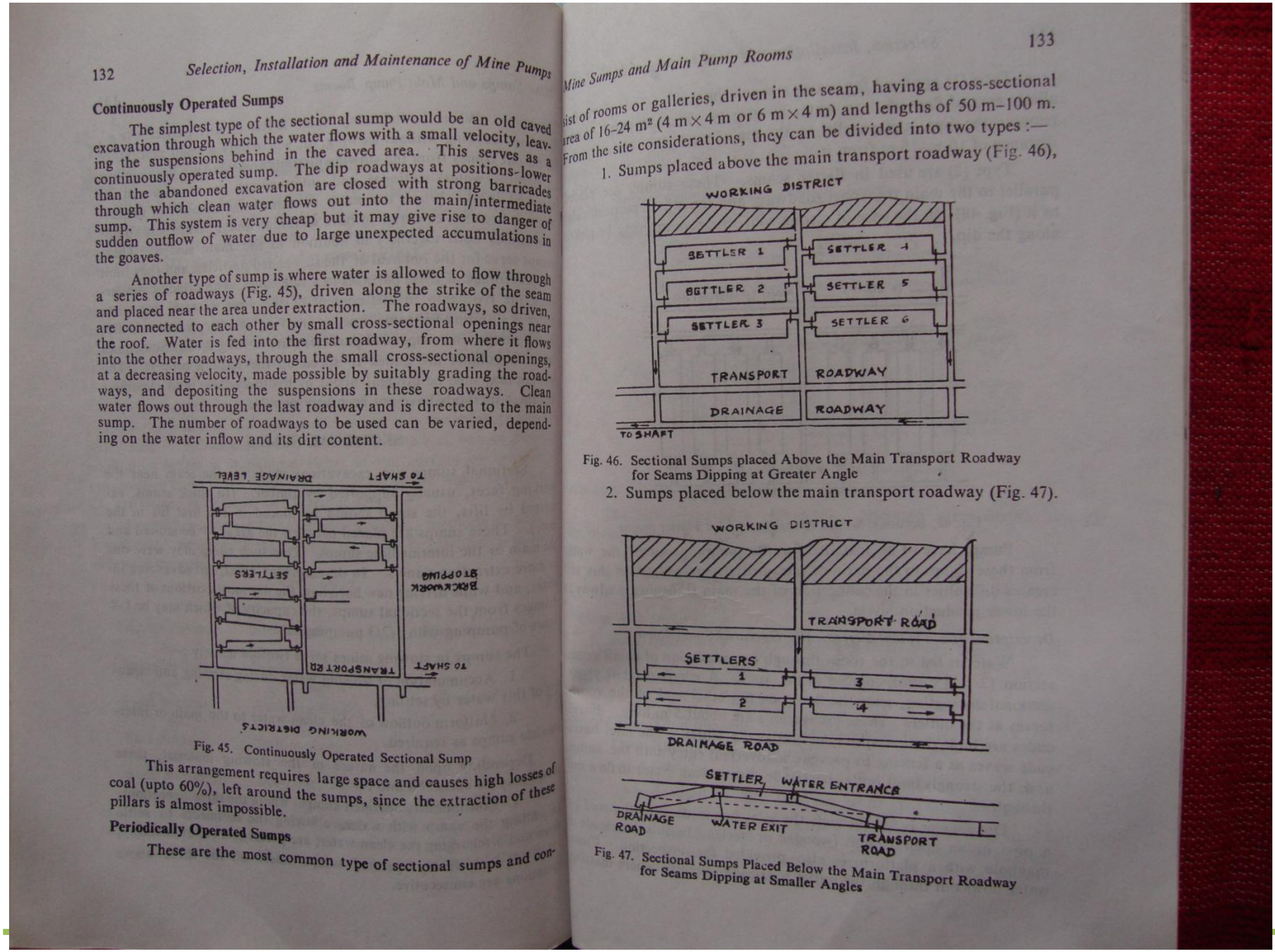
1. Accumulation of stowing water during stowing and cleaning of this water by settling,

2. Uniform outflow of the clean water to the main or intermediate sumps as required.

Depending upon the nature of the stowing material, these sumps may be classified into :—

1. Continuously operated sumps, where the three operations, *i.e.*, filling the sump with water, allowing the sediments to settle down and discharging the clean water, are performed simultaneously,

2. Periodically operated sumps where all the three above operations are consecutive.



Continuously Operated Sumps

The simplest type of the sectional sump would be an old caved excavation through which the water flows with a small velocity, leaving the suspensions behind in the caved area. This serves as a continuously operated sump. The dip roadways at positions-lower than the abandoned excavation are closed with strong barricades through which clean water flows out into the main/intermediate sump. This system is very cheap but it may give rise to danger of sudden outflow of water due to large unexpected accumulations in the goaves.

Another type of sump is where water is allowed to flow through a series of roadways (Fig. 45), driven along the strike of the seam and placed near the area under extraction. The roadways, so driven, are connected to each other by small cross-sectional openings near the roof. Water is fed into the first roadway, from where it flows into the other roadways, through the small cross-sectional openings, at a decreasing velocity, made possible by suitably grading the roadways, and depositing the suspensions in these roadways. Clean water flows out through the last roadway and is directed to the main sump. The number of roadways to be used can be varied, depending on the water inflow and its dirt content.

DRAINAGE LEVEL
TO SHAFT
SETTLERS
BRICKWORK STOPPING
TRANSPORT RD
TO SHAFT
WORKING DISTRICTS

Fig. 45. Continuously Operated Sectional Sump

This arrangement requires large space and causes high losses of coal (upto 60%), left around the sumps, since the extraction of these pillars is almost impossible.

Periodically Operated Sumps

These are the most common type of sectional sumps and con-

sist of rooms or galleries, driven in the seam, having a cross-sectional area of 16–24 m² (4 m × 4 m or 6 m × 4 m) and lengths of 50 m–100 m. From the site considerations, they can be divided into two types :—

1. Sumps placed above the main transport roadway (Fig. 46),

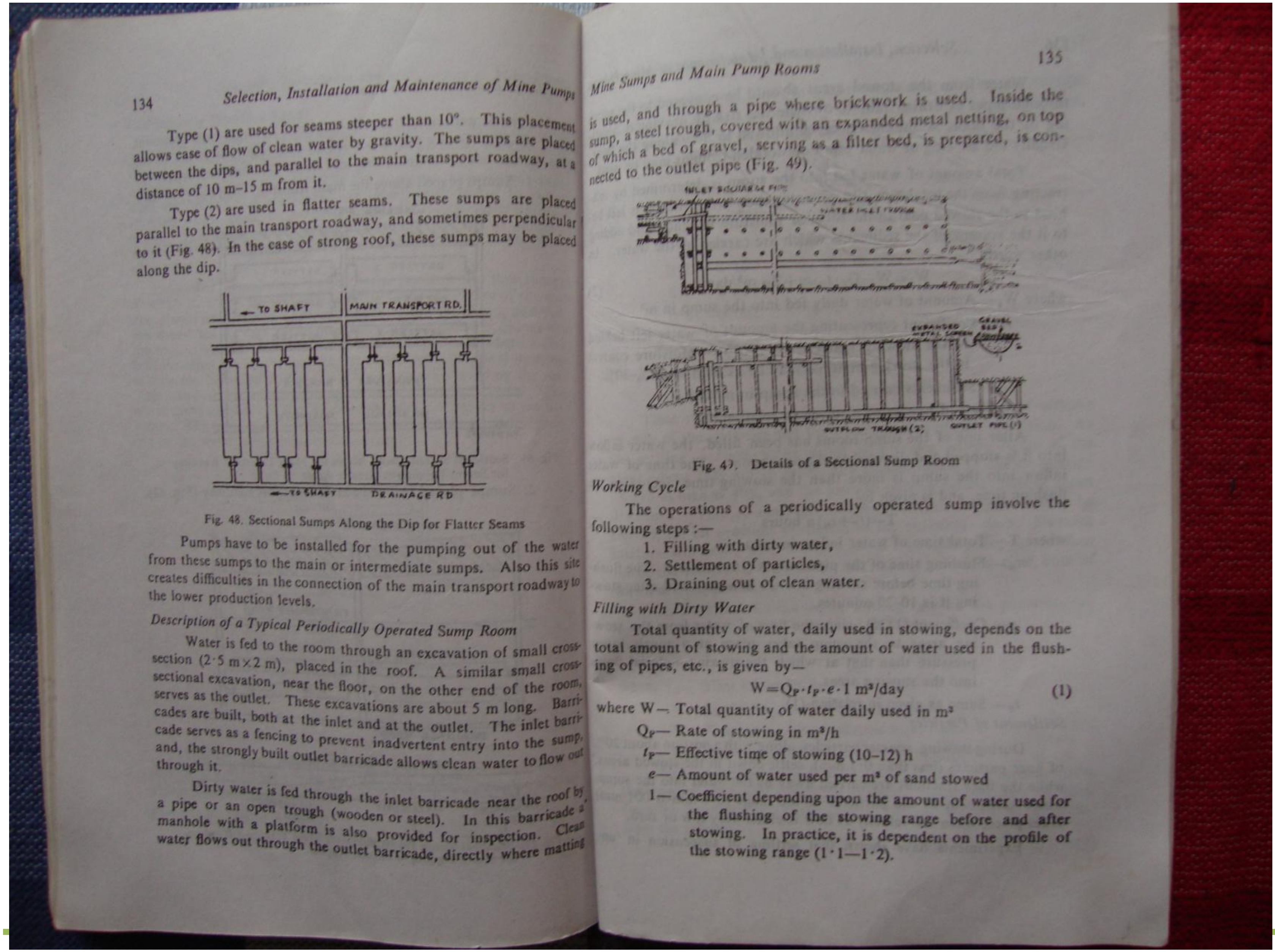
WORKING DISTRICT
SETTLER 1
SETTLER 2
SETTLER 3
SETTLER 4
SETTLER 5
SETTLER 6
TRANSPORT ROADWAY
DRAINAGE ROADWAY
TO SHAFT

Fig. 46. Sectional Sumps placed Above the Main Transport Roadway for Seams Dipping at Greater Angle

2. Sumps placed below the main transport roadway (Fig. 47).

WORKING DISTRICT
TRANSPORT ROAD
SETTLERS
1
2
3
4
DRAINAGE ROAD
SETTLER, WATER ENTRANCE
DRAINAGE ROAD
WATER EXIT
TRANSPORT ROAD

Fig. 47. Sectional Sumps Placed Below the Main Transport Roadway for Seams Dipping at Smaller Angles



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Type (1) are used for seams steeper than 10°. This placement allows ease of flow of clean water by gravity. The sumps are placed between the dips, and parallel to the main transport roadway, at a distance of 10 m–15 m from it.

Type (2) are used in flatter seams. These sumps are placed parallel to the main transport roadway, and sometimes perpendicular to it (Fig. 48). In the case of strong roof, these sumps may be placed along the dip.

Fig. 48. Sectional Sumps Along the Dip for Flatter Seams

Pumps have to be installed for the pumping out of the water from these sumps to the main or intermediate sumps. Also this site creates difficulties in the connection of the main transport roadway to the lower production levels.

Description of a Typical Periodically Operated Sump Room

Water is fed to the room through an excavation of small cross-section (2·5 m × 2 m), placed in the roof. A similar small cross-sectional excavation, near the floor, on the other end of the room, serves as the outlet. These excavations are about 5 m long. Barricades are built, both at the inlet and at the outlet. The inlet barricade serves as a fencing to prevent inadvertent entry into the sump, and, the strongly built outlet barricade allows clean water to flow out through it.

Dirty water is fed through the inlet barricade near the roof by a pipe or an open trough (wooden or steel). In this barricade a manhole with a platform is also provided for inspection. Clean water flows out through the outlet barricade, directly where matting is used, and through a pipe where brickwork is used. Inside the sump, a steel trough, covered with an expanded metal netting, on top of which a bed of gravel, serving as a filter bed, is prepared, is connected to the outlet pipe (Fig. 49).

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Fig. 49. Details of a Sectional Sump Room

Working Cycle

The operations of a periodically operated sump involve the following steps :—

1. Filling with dirty water,
2. Settlement of particles,
3. Draining out of clean water.

Filling with Dirty Water

Total quantity of water, daily used in stowing, depends on the total amount of stowing and the amount of water used in the flushing of pipes, etc., is given by—

$$W = Q_p \cdot t_p \cdot e \cdot 1 \text{ m}^3\text{/day} \qquad (1)$$

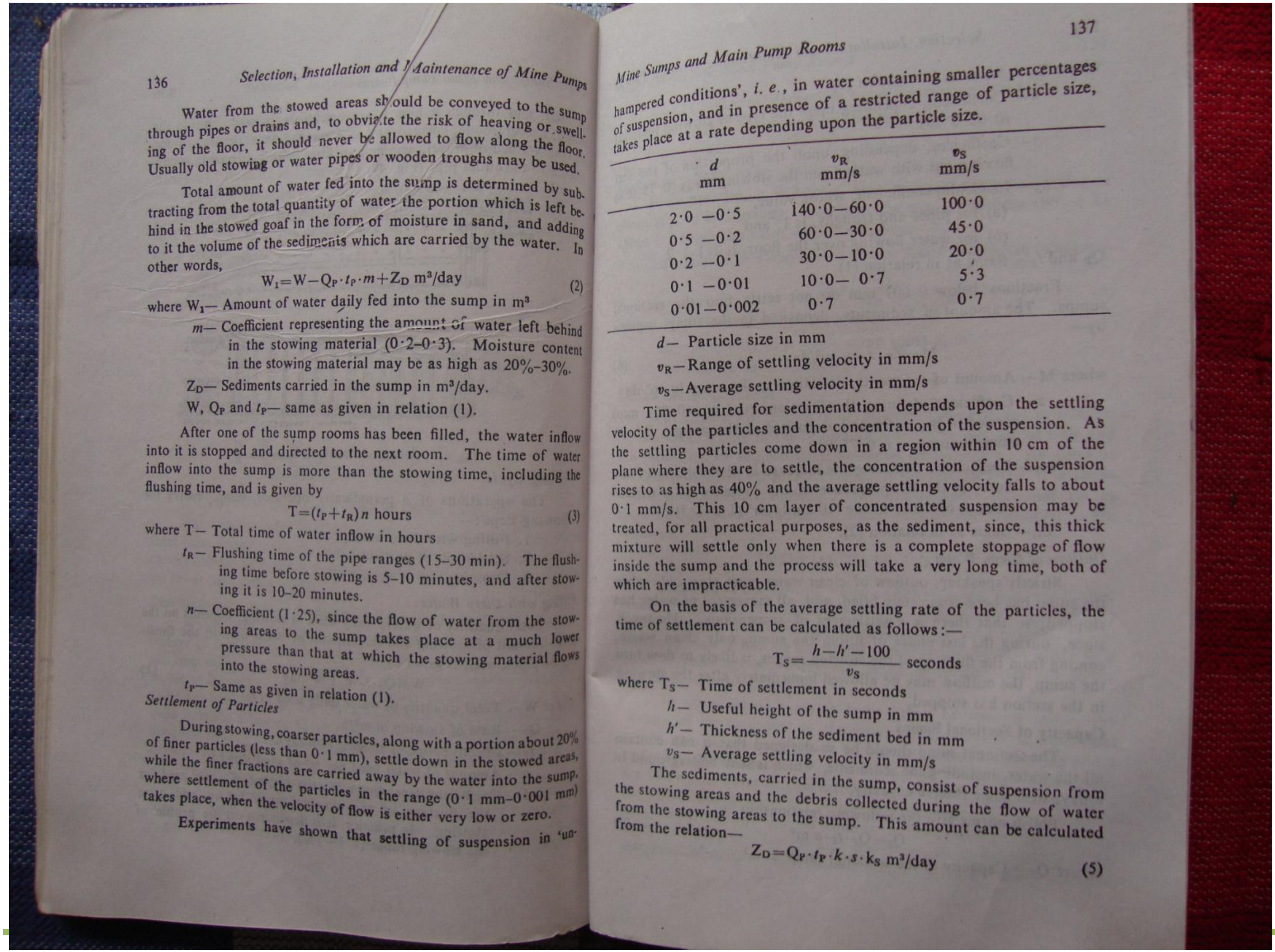
where W— Total quantity of water daily used in m³

Q_p— Rate of stowing in m³/h

t_p— Effective time of stowing (10–12) h

e— Amount of water used per m³ of sand stowed

1— Coefficient depending upon the amount of water used for the flushing of the stowing range before and after stowing. In practice, it is dependent on the profile of the stowing range (1·1—1·2).



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Water from the stowed areas should be conveyed to the sump through pipes or drains and, to obviate the risk of heaving or swelling of the floor, it should never be allowed to flow along the floor. Usually old stowing or water pipes or wooden troughs may be used.

Total amount of water fed into the sump is determined by subtracting from the total quantity of water the portion which is left behind in the stowed goaf in the form of moisture in sand, and adding to it the volume of the sediments which are carried by the water. In other words,

$$W_1 = W - Q_P \cdot t_P \cdot m + Z_D \text{ m}^3/\text{day} \qquad (2)$$

where W_1— Amount of water daily fed into the sump in m^3

m— Coefficient representing the amount of water left behind in the stowing material (0·2–0·3). Moisture content in the stowing material may be as high as 20%–30%.

Z_D— Sediments carried in the sump in m^3/day.

W, Q_P and t_P— same as given in relation (1).

After one of the sump rooms has been filled, the water inflow into it is stopped and directed to the next room. The time of water inflow into the sump is more than the stowing time, including the flushing time, and is given by

$$T = (t_P + t_R)\, n \text{ hours} \qquad (3)$$

where T— Total time of water inflow in hours

t_R— Flushing time of the pipe ranges (15–30 min). The flushing time before stowing is 5–10 minutes, and after stowing it is 10–20 minutes.

n— Coefficient (1·25), since the flow of water from the stowing areas to the sump takes place at a much lower pressure than that at which the stowing material flows into the stowing areas.

t_P— Same as given in relation (1).

Settlement of Particles

During stowing, coarser particles, along with a portion about 20% of finer particles (less than 0·1 mm), settle down in the stowed areas, while the finer fractions are carried away by the water into the sump, where settlement of the particles in the range (0·1 mm–0·001 mm) takes place, when the velocity of flow is either very low or zero.

Experiments have shown that settling of suspension in 'unhampered conditions', *i. e.*, in water containing smaller percentages of suspension, and in presence of a restricted range of particle size, takes place at a rate depending upon the particle size.

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d mm	v_R mm/s	v_S mm/s
2·0 –0·5	140·0–60·0	100·0
0·5 –0·2	60·0–30·0	45·0
0·2 –0·1	30·0–10·0	20·0
0·1 –0·01	10·0– 0·7	5·3
0·01–0·002	0·7	0·7

d— Particle size in mm

v_R—Range of settling velocity in mm/s

v_S—Average settling velocity in mm/s

Time required for sedimentation depends upon the settling velocity of the particles and the concentration of the suspension. As the settling particles come down in a region within 10 cm of the plane where they are to settle, the concentration of the suspension rises to as high as 40% and the average settling velocity falls to about 0·1 mm/s. This 10 cm layer of concentrated suspension may be treated, for all practical purposes, as the sediment, since, this thick mixture will settle only when there is a complete stoppage of flow inside the sump and the process will take a very long time, both of which are impracticable.

On the basis of the average settling rate of the particles, the time of settlement can be calculated as follows:—

$$T_S = \frac{h - h' - 100}{v_S} \text{ seconds}$$

where T_S— Time of settlement in seconds

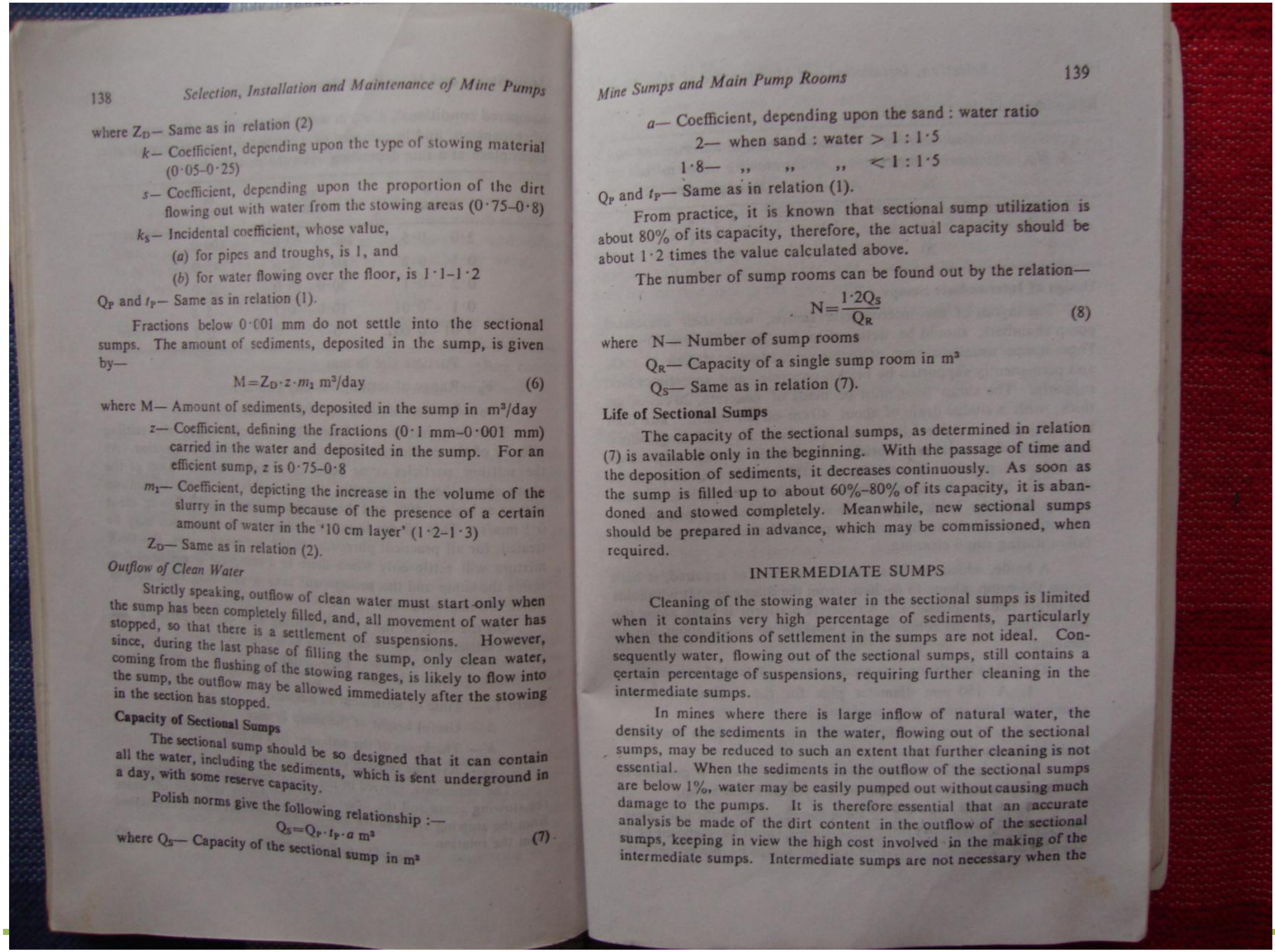
h— Useful height of the sump in mm

h'— Thickness of the sediment bed in mm

v_S— Average settling velocity in mm/s

The sediments, carried in the sump, consist of suspension from the stowing areas and the debris collected during the flow of water from the stowing areas to the sump. This amount can be calculated from the relation—

$$Z_D = Q_P \cdot t_P \cdot k \cdot s \cdot k_S \text{ m}^3/\text{day} \qquad (5)$$



where Z_D— Same as in relation (2)

k— Coefficient, depending upon the type of stowing material (0·05–0·25)

s— Coefficient, depending upon the proportion of the dirt flowing out with water from the stowing areas (0·75–0·8)

k_S— Incidental coefficient, whose value,

(*a*) for pipes and troughs, is 1, and

(*b*) for water flowing over the floor, is 1·1–1·2

Q_P and t_P— Same as in relation (1).

Fractions below 0·001 mm do not settle into the sectional sumps. The amount of sediments, deposited in the sump, is given by—

$$M = Z_D \cdot z \cdot m_1 \text{ m}^3/\text{day} \qquad (6)$$

where M— Amount of sediments, deposited in the sump in m^3/day

z— Coefficient, defining the fractions (0·1 mm–0·001 mm) carried in the water and deposited in the sump. For an efficient sump, *z* is 0·75–0·8

m_1— Coefficient, depicting the increase in the volume of the slurry in the sump because of the presence of a certain amount of water in the '10 cm layer' (1·2–1·3)

Z_D— Same as in relation (2).

Outflow of Clean Water

Strictly speaking, outflow of clean water must start only when the sump has been completely filled, and, all movement of water has stopped, so that there is a settlement of suspensions. However, since, during the last phase of filling the sump, only clean water, coming from the flushing of the stowing ranges, is likely to flow into the sump, the outflow may be allowed immediately after the stowing in the section has stopped.

Capacity of Sectional Sumps

The sectional sump should be so designed that it can contain all the water, including the sediments, which is sent underground in a day, with some reserve capacity.

Polish norms give the following relationship :—

$$Q_S = Q_P \cdot t_P \cdot a \text{ m}^3 \qquad (7)$$

where Q_S— Capacity of the sectional sump in m^3

a— Coefficient, depending upon the sand : water ratio

2— when sand : water $> 1 : 1·5$

1·8— „ „ „ $< 1 : 1·5$

Q_P and t_P— Same as in relation (1).

From practice, it is known that sectional sump utilization is about 80% of its capacity, therefore, the actual capacity should be about 1·2 times the value calculated above.

The number of sump rooms can be found out by the relation—

$$N = \frac{1·2 Q_S}{Q_R} \qquad (8)$$

where N— Number of sump rooms

Q_R— Capacity of a single sump room in m^3

Q_S— Same as in relation (7).

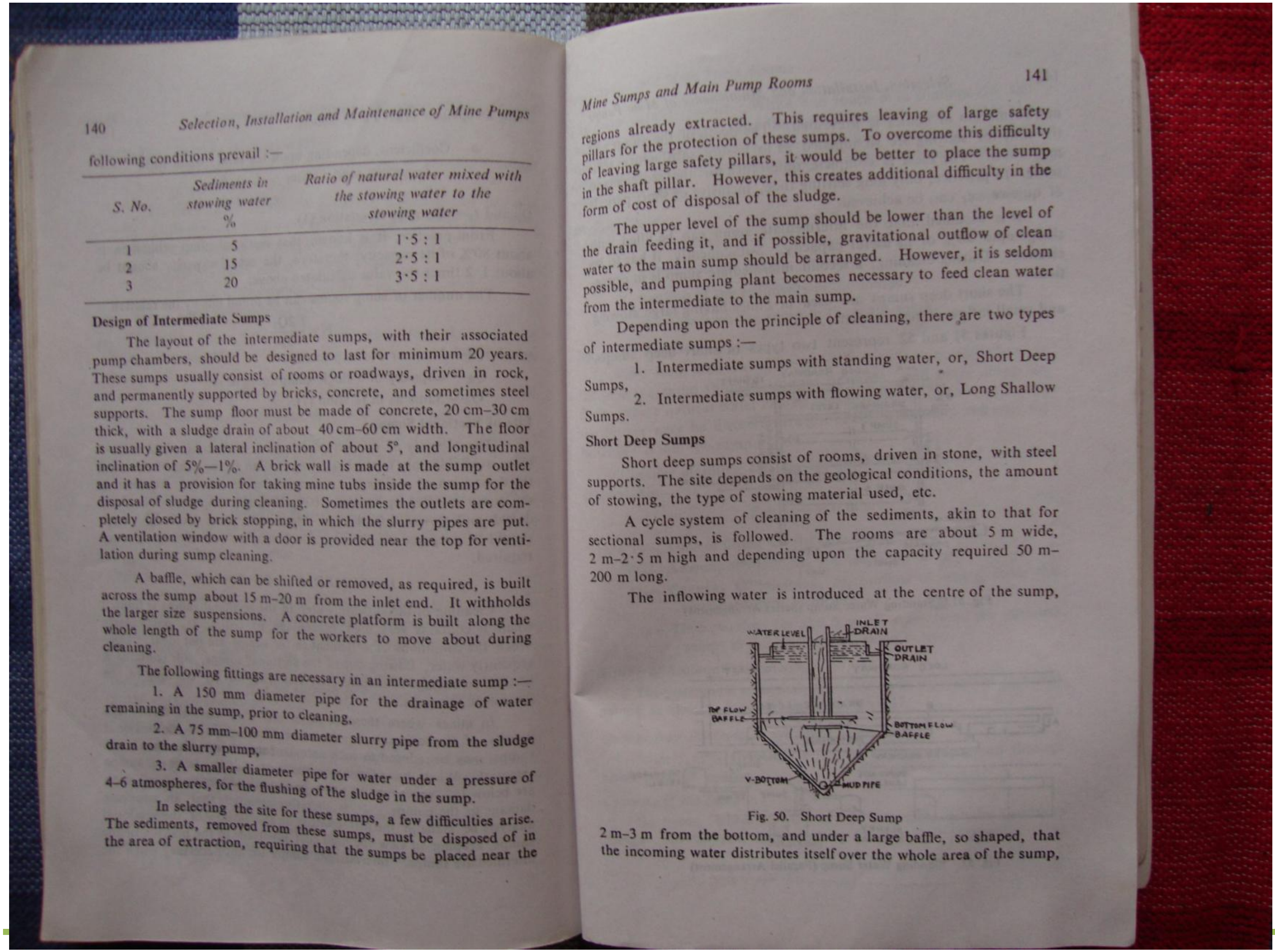
Life of Sectional Sumps

The capacity of the sectional sumps, as determined in relation (7) is available only in the beginning. With the passage of time and the deposition of sediments, it decreases continuously. As soon as the sump is filled up to about 60%–80% of its capacity, it is abandoned and stowed completely. Meanwhile, new sectional sumps should be prepared in advance, which may be commissioned, when required.

INTERMEDIATE SUMPS

Cleaning of the stowing water in the sectional sumps is limited when it contains very high percentage of sediments, particularly when the conditions of settlement in the sumps are not ideal. Consequently water, flowing out of the sectional sumps, still contains a certain percentage of suspensions, requiring further cleaning in the intermediate sumps.

In mines where there is large inflow of natural water, the density of the sediments in the water, flowing out of the sectional sumps, may be reduced to such an extent that further cleaning is not essential. When the sediments in the outflow of the sectional sumps are below 1%, water may be easily pumped out without causing much damage to the pumps. It is therefore essential that an accurate analysis be made of the dirt content in the outflow of the sectional sumps, keeping in view the high cost involved in the making of the intermediate sumps. Intermediate sumps are not necessary when the


WATER LEVEL
INLET DRAIN
OUTLET DRAIN
TOP FLOW BAFFLE
BOTTOM FLOW BAFFLE
V-BOTTOM
MUD PIPE

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following conditions prevail :—

S. No.	*Sediments in stowing water %*	*Ratio of natural water mixed with the stowing water to the stowing water*
1	5	1·5 : 1
2	15	2·5 : 1
3	20	3·5 : 1

Design of Intermediate Sumps

The layout of the intermediate sumps, with their associated pump chambers, should be designed to last for minimum 20 years. These sumps usually consist of rooms or roadways, driven in rock, and permanently supported by bricks, concrete, and sometimes steel supports. The sump floor must be made of concrete, 20 cm–30 cm thick, with a sludge drain of about 40 cm–60 cm width. The floor is usually given a lateral inclination of about 5°, and longitudinal inclination of 5%—1%. A brick wall is made at the sump outlet and it has a provision for taking mine tubs inside the sump for the disposal of sludge during cleaning. Sometimes the outlets are completely closed by brick stopping, in which the slurry pipes are put. A ventilation window with a door is provided near the top for ventilation during sump cleaning.

A baffle, which can be shifted or removed, as required, is built across the sump about 15 m–20 m from the inlet end. It withholds the larger size suspensions. A concrete platform is built along the whole length of the sump for the workers to move about during cleaning.

The following fittings are necessary in an intermediate sump :—

1. A 150 mm diameter pipe for the drainage of water remaining in the sump, prior to cleaning,
2. A 75 mm–100 mm diameter slurry pipe from the sludge drain to the slurry pump,
3. A smaller diameter pipe for water under a pressure of 4–6 atmospheres, for the flushing of the sludge in the sump.

In selecting the site for these sumps, a few difficulties arise. The sediments, removed from these sumps, must be disposed of in the area of extraction, requiring that the sumps be placed near the regions already extracted. This requires leaving of large safety pillars for the protection of these sumps. To overcome this difficulty of leaving large safety pillars, it would be better to place the sump in the shaft pillar. However, this creates additional difficulty in the form of cost of disposal of the sludge.

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The upper level of the sump should be lower than the level of the drain feeding it, and if possible, gravitational outflow of clean water to the main sump should be arranged. However, it is seldom possible, and pumping plant becomes necessary to feed clean water from the intermediate to the main sump.

Depending upon the principle of cleaning, there are two types of intermediate sumps :—

1. Intermediate sumps with standing water, or, Short Deep Sumps,
2. Intermediate sumps with flowing water, or, Long Shallow Sumps.

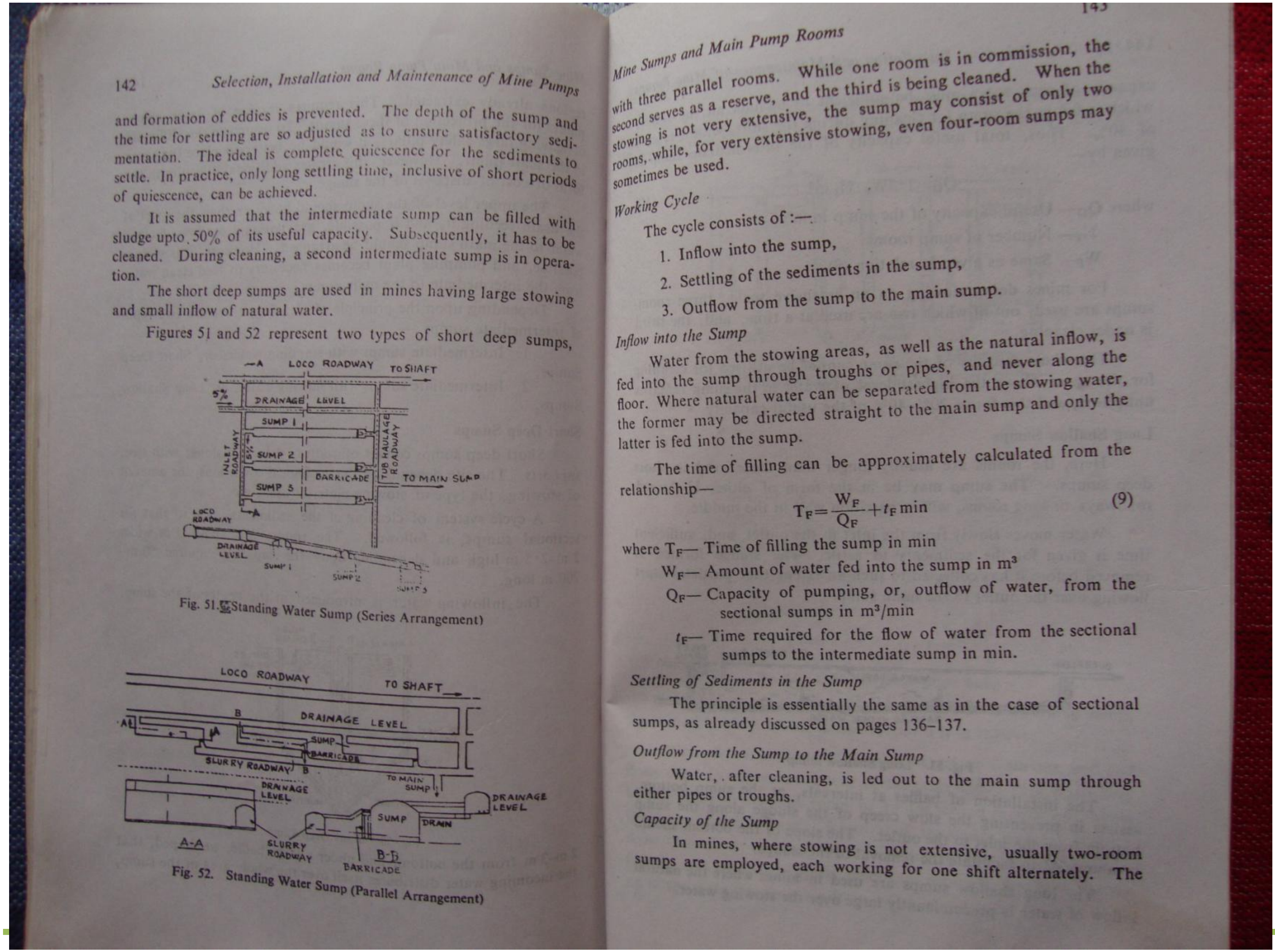
Short Deep Sumps

Short deep sumps consist of rooms, driven in stone, with steel supports. The site depends on the geological conditions, the amount of stowing, the type of stowing material used, etc.

A cycle system of cleaning of the sediments, akin to that for sectional sumps, is followed. The rooms are about 5 m wide, 2 m–2·5 m high and depending upon the capacity required 50 m–200 m long.

The inflowing water is introduced at the centre of the sump, 2 m–3 m from the bottom, and under a large baffle, so shaped, that the incoming water distributes itself over the whole area of the sump,

Fig. 50. Short Deep Sump



and formation of eddies is prevented. The depth of the sump and the time for settling are so adjusted as to ensure satisfactory sedimentation. The ideal is complete quiescence for the sediments to settle. In practice, only long settling time, inclusive of short periods of quiescence, can be achieved.

It is assumed that the intermediate sump can be filled with sludge upto 50% of its useful capacity. Subsequently, it has to be cleaned. During cleaning, a second intermediate sump is in operation.

The short deep sumps are used in mines having large stowing and small inflow of natural water.

Figures 51 and 52 represent two types of short deep sumps,

A
LOCO ROADWAY
TO SHAFT
5%
DRAINAGE LEVEL
SUMP 1
SUMP 2
SUMP 3
5%
INLET ROADWAY
TUB HAULAGE ROADWAY
BARRICADE
TO MAIN SUMP
A
LOCO ROADWAY
DRAINAGE LEVEL
SUMP 1
SUMP 2
SUMP 3

Fig. 51. Standing Water Sump (Series Arrangement)

LOCO ROADWAY
TO SHAFT
A
B
DRAINAGE LEVEL
A
SUMP
BARRICADE
SLURRY ROADWAY
B
TO MAIN SUMP
DRAINAGE LEVEL
DRAINAGE LEVEL
SUMP
DRAIN
A-A
SLURRY ROADWAY
B-B
BARRICADE

Fig. 52. Standing Water Sump (Parallel Arrangement)

with three parallel rooms. While one room is in commission, the second serves as a reserve, and the third is being cleaned. When the stowing is not very extensive, the sump may consist of only two rooms, while, for very extensive stowing, even four-room sumps may sometimes be used.

Working Cycle

The cycle consists of :—

1. Inflow into the sump,
2. Settling of the sediments in the sump,
3. Outflow from the sump to the main sump.

Inflow into the Sump

Water from the stowing areas, as well as the natural inflow, is fed into the sump through troughs or pipes, and never along the floor. Where natural water can be separated from the stowing water, the former may be directed straight to the main sump and only the latter is fed into the sump.

The time of filling can be approximately calculated from the relationship—

$$T_F = \frac{W_F}{Q_F} + t_F \text{ min} \tag{9}$$

where T_F— Time of filling the sump in min

W_F— Amount of water fed into the sump in m³

Q_F— Capacity of pumping, or, outflow of water, from the sectional sumps in m³/min

t_F— Time required for the flow of water from the sectional sumps to the intermediate sump in min.

Settling of Sediments in the Sump

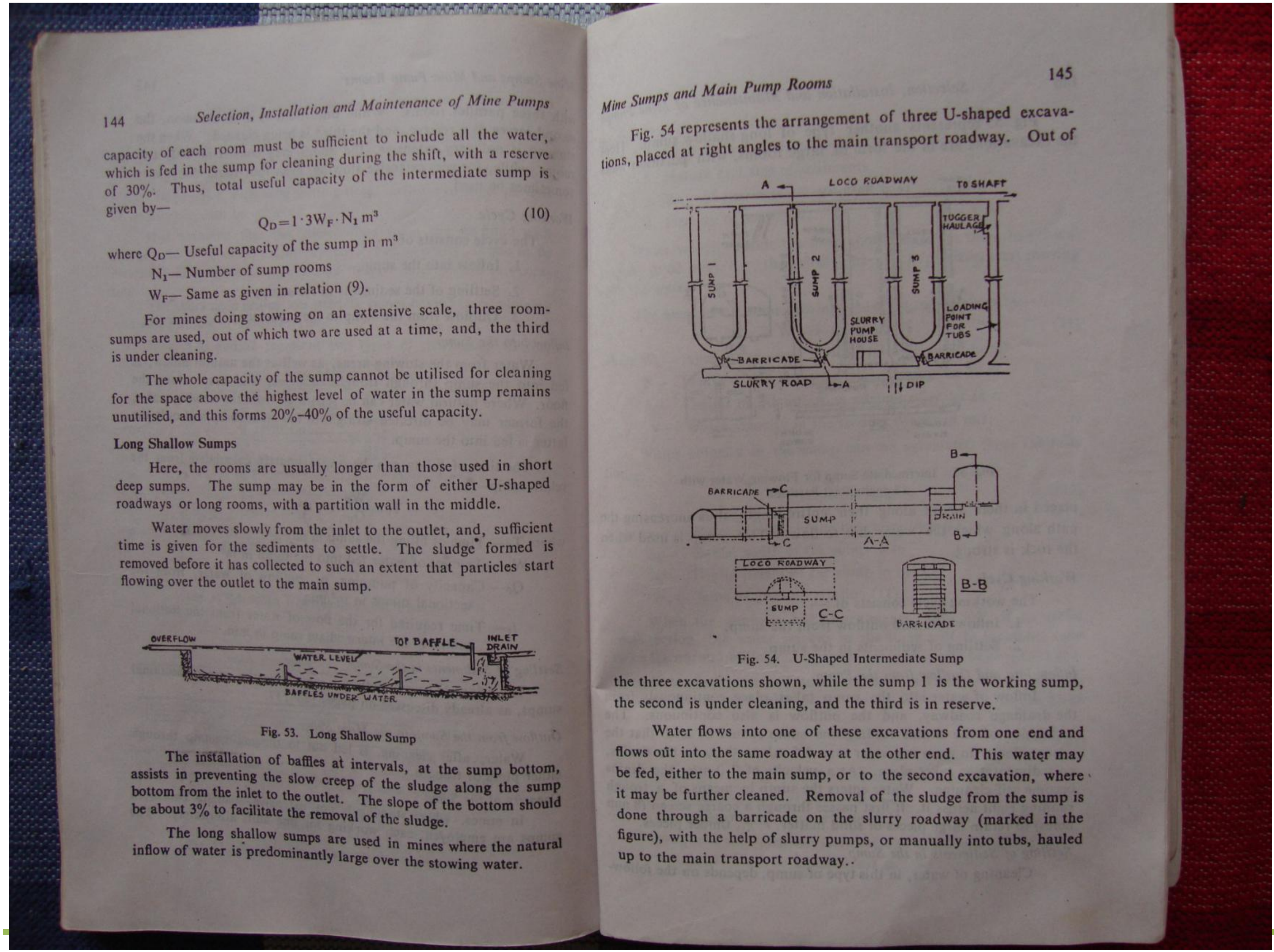
The principle is essentially the same as in the case of sectional sumps, as already discussed on pages 136–137.

Outflow from the Sump to the Main Sump

Water, after cleaning, is led out to the main sump through either pipes or troughs.

Capacity of the Sump

In mines, where stowing is not extensive, usually two-room sumps are employed, each working for one shift alternately. The



capacity of each room must be sufficient to include all the water, which is fed in the sump for cleaning during the shift, with a reserve of 30%. Thus, total useful capacity of the intermediate sump is given by—

$$Q_D = 1{\cdot}3 W_F \cdot N_1 \ m^3 \qquad (10)$$

where Q_D— Useful capacity of the sump in m^3

N_1— Number of sump rooms

W_F— Same as given in relation (9).

For mines doing stowing on an extensive scale, three room-sumps are used, out of which two are used at a time, and, the third is under cleaning.

The whole capacity of the sump cannot be utilised for cleaning for the space above the highest level of water in the sump remains unutilised, and this forms 20%–40% of the useful capacity.

Long Shallow Sumps

Here, the rooms are usually longer than those used in short deep sumps. The sump may be in the form of either U-shaped roadways or long rooms, with a partition wall in the middle.

Water moves slowly from the inlet to the outlet, and, sufficient time is given for the sediments to settle. The sludge formed is removed before it has collected to such an extent that particles start flowing over the outlet to the main sump.

OVERFLOW
TOP BAFFLE
INLET DRAIN
WATER LEVEL
BAFFLES UNDER WATER

Fig. 53. Long Shallow Sump

The installation of baffles at intervals, at the sump bottom, assists in preventing the slow creep of the sludge along the sump bottom from the inlet to the outlet. The slope of the bottom should be about 3% to facilitate the removal of the sludge.

The long shallow sumps are used in mines where the natural inflow of water is predominantly large over the stowing water.

Fig. 54 represents the arrangement of three U-shaped excavations, placed at right angles to the main transport roadway. Out of

A
LOCO ROADWAY
TO SHAFT
TUGGER HAULAGE
SUMP 1
SUMP 2
SUMP 3
SLURRY PUMP HOUSE
LOADING POINT FOR TUBS
BARRICADE
BARRICADE
SLURRY ROAD
A
DIP
B
BARRICADE
C
SUMP
DRAIN
C
A-A
B
LOCO ROADWAY
SUMP
C-C
B-B
BARRICADE

Fig. 54. U-Shaped Intermediate Sump

the three excavations shown, while the sump 1 is the working sump, the second is under cleaning, and the third is in reserve.

Water flows into one of these excavations from one end and flows out into the same roadway at the other end. This water may be fed, either to the main sump, or to the second excavation, where it may be further cleaned. Removal of the sludge from the sump is done through a barricade on the slurry roadway (marked in the figure), with the help of slurry pumps, or manually into tubs, hauled up to the main transport roadway.

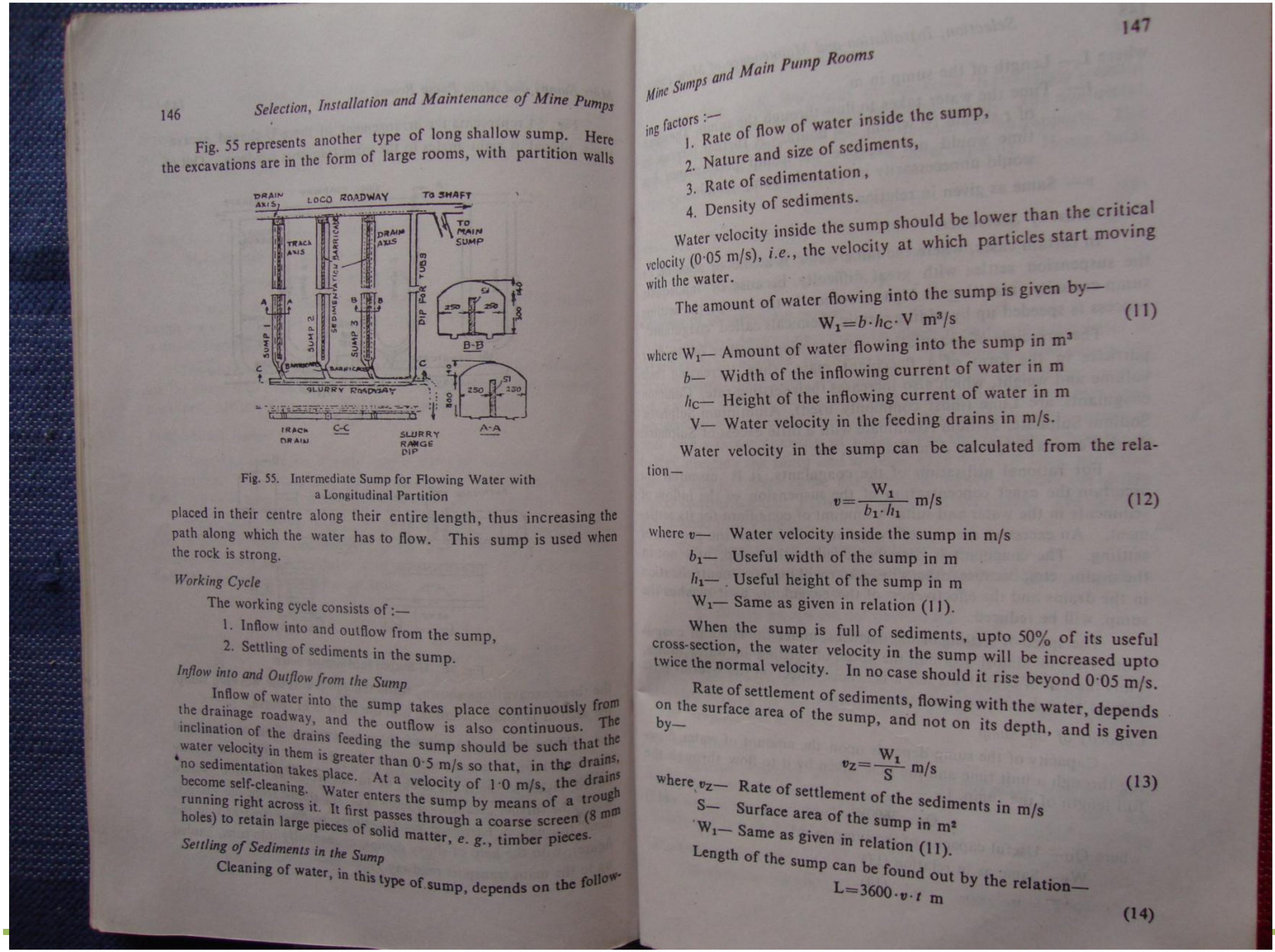

DRAIN AXIS
LOCO ROADWAY
TO SHAFT
TO MAIN SUMP
TRACK AXIS
BARRICADE
DRAIN AXIS
SEDIMENTATION BARRICADE
DIP FOR TUBS
SUMP 1
SUMP 2
SUMP 3
A
B
C
BARRICADE
SLURRY ROADWAY
250
51
140
300
B-B
40
800
A-A
TRACK DRAIN
C-C
SLURRY RANGE DIP

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Fig. 55 represents another type of long shallow sump. Here the excavations are in the form of large rooms, with partition walls placed in their centre along their entire length, thus increasing the path along which the water has to flow. This sump is used when the rock is strong.

Fig. 55. Intermediate Sump for Flowing Water with a Longitudinal Partition

Working Cycle

The working cycle consists of :—

1. Inflow into and outflow from the sump,
2. Settling of sediments in the sump.

Inflow into and Outflow from the Sump

Inflow of water into the sump takes place continuously from the drainage roadway, and the outflow is also continuous. The inclination of the drains feeding the sump should be such that the water velocity in them is greater than 0·5 m/s so that, in the drains, no sedimentation takes place. At a velocity of 1·0 m/s, the drains become self-cleaning. Water enters the sump by means of a trough running right across it. It first passes through a coarse screen (8 mm holes) to retain large pieces of solid matter, *e. g.*, timber pieces.

Settling of Sediments in the Sump

Cleaning of water, in this type of sump, depends on the following factors :—

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1. Rate of flow of water inside the sump,
2. Nature and size of sediments,
3. Rate of sedimentation,
4. Density of sediments.

Water velocity inside the sump should be lower than the critical velocity (0·05 m/s), *i.e.*, the velocity at which particles start moving with the water.

The amount of water flowing into the sump is given by—

$$W_1 = b \cdot h_C \cdot V \ \text{m}^3/\text{s} \qquad (11)$$

where W_1— Amount of water flowing into the sump in m³
b— Width of the inflowing current of water in m
h_C— Height of the inflowing current of water in m
V— Water velocity in the feeding drains in m/s.

Water velocity in the sump can be calculated from the relation—

$$v = \frac{W_1}{b_1 \cdot h_1} \ \text{m/s} \qquad (12)$$

where v— Water velocity inside the sump in m/s
b_1— Useful width of the sump in m
h_1— Useful height of the sump in m
W_1— Same as given in relation (11).

When the sump is full of sediments, upto 50% of its useful cross-section, the water velocity in the sump will be increased upto twice the normal velocity. In no case should it rise beyond 0·05 m/s.

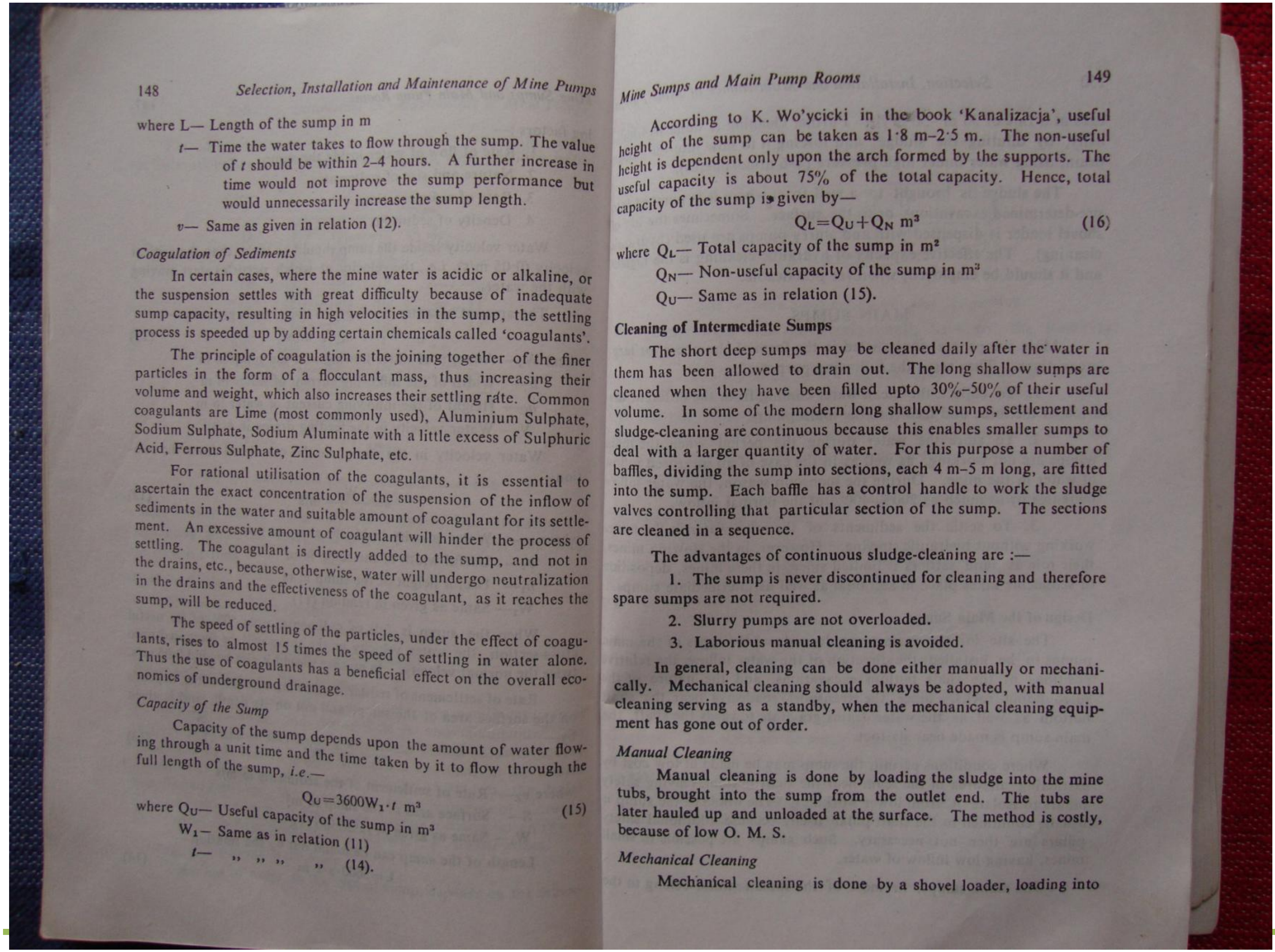
Rate of settlement of sediments, flowing with the water, depends on the surface area of the sump, and not on its depth, and is given by—

$$v_Z = \frac{W_1}{S} \ \text{m/s} \qquad (13)$$

where v_Z— Rate of settlement of the sediments in m/s
S— Surface area of the sump in m²
W_1— Same as given in relation (11).

Length of the sump can be found out by the relation—

$$L = 3600 \cdot v \cdot t \ \text{m} \qquad (14)$$



where L— Length of the sump in m

t— Time the water takes to flow through the sump. The value of t should be within 2–4 hours. A further increase in time would not improve the sump performance but would unnecessarily increase the sump length.

v— Same as given in relation (12).

Coagulation of Sediments

In certain cases, where the mine water is acidic or alkaline, or the suspension settles with great difficulty because of inadequate sump capacity, resulting in high velocities in the sump, the settling process is speeded up by adding certain chemicals called 'coagulants'.

The principle of coagulation is the joining together of the finer particles in the form of a flocculant mass, thus increasing their volume and weight, which also increases their settling rate. Common coagulants are Lime (most commonly used), Aluminium Sulphate, Sodium Sulphate, Sodium Aluminate with a little excess of Sulphuric Acid, Ferrous Sulphate, Zinc Sulphate, etc.

For rational utilisation of the coagulants, it is essential to ascertain the exact concentration of the suspension of the inflow of sediments in the water and suitable amount of coagulant for its settlement. An excessive amount of coagulant will hinder the process of settling. The coagulant is directly added to the sump, and not in the drains, etc., because, otherwise, water will undergo neutralization in the drains and the effectiveness of the coagulant, as it reaches the sump, will be reduced.

The speed of settling of the particles, under the effect of coagulants, rises to almost 15 times the speed of settling in water alone. Thus the use of coagulants has a beneficial effect on the overall economics of underground drainage.

Capacity of the Sump

Capacity of the sump depends upon the amount of water flowing through a unit time and the time taken by it to flow through the full length of the sump, *i.e.*—

$$Q_U = 3600 W_1 \cdot t \text{ m}^3 \qquad (15)$$

where Q_U— Useful capacity of the sump in m^3

W_1— Same as in relation (11)

t— ,, ,, ,, ,, (14).

According to K. Wo'ycicki in the book 'Kanalizacja', useful height of the sump can be taken as 1·8 m–2·5 m. The non-useful height is dependent only upon the arch formed by the supports. The useful capacity is about 75% of the total capacity. Hence, total capacity of the sump is given by—

$$Q_L = Q_U + Q_N \text{ m}^3 \qquad (16)$$

where Q_L— Total capacity of the sump in m^2

Q_N— Non-useful capacity of the sump in m^3

Q_U— Same as in relation (15).

Cleaning of Intermediate Sumps

The short deep sumps may be cleaned daily after the water in them has been allowed to drain out. The long shallow sumps are cleaned when they have been filled upto 30%–50% of their useful volume. In some of the modern long shallow sumps, settlement and sludge-cleaning are continuous because this enables smaller sumps to deal with a larger quantity of water. For this purpose a number of baffles, dividing the sump into sections, each 4 m–5 m long, are fitted into the sump. Each baffle has a control handle to work the sludge valves controlling that particular section of the sump. The sections are cleaned in a sequence.

The advantages of continuous sludge-cleaning are :—

1. The sump is never discontinued for cleaning and therefore spare sumps are not required.
2. Slurry pumps are not overloaded.
3. Laborious manual cleaning is avoided.

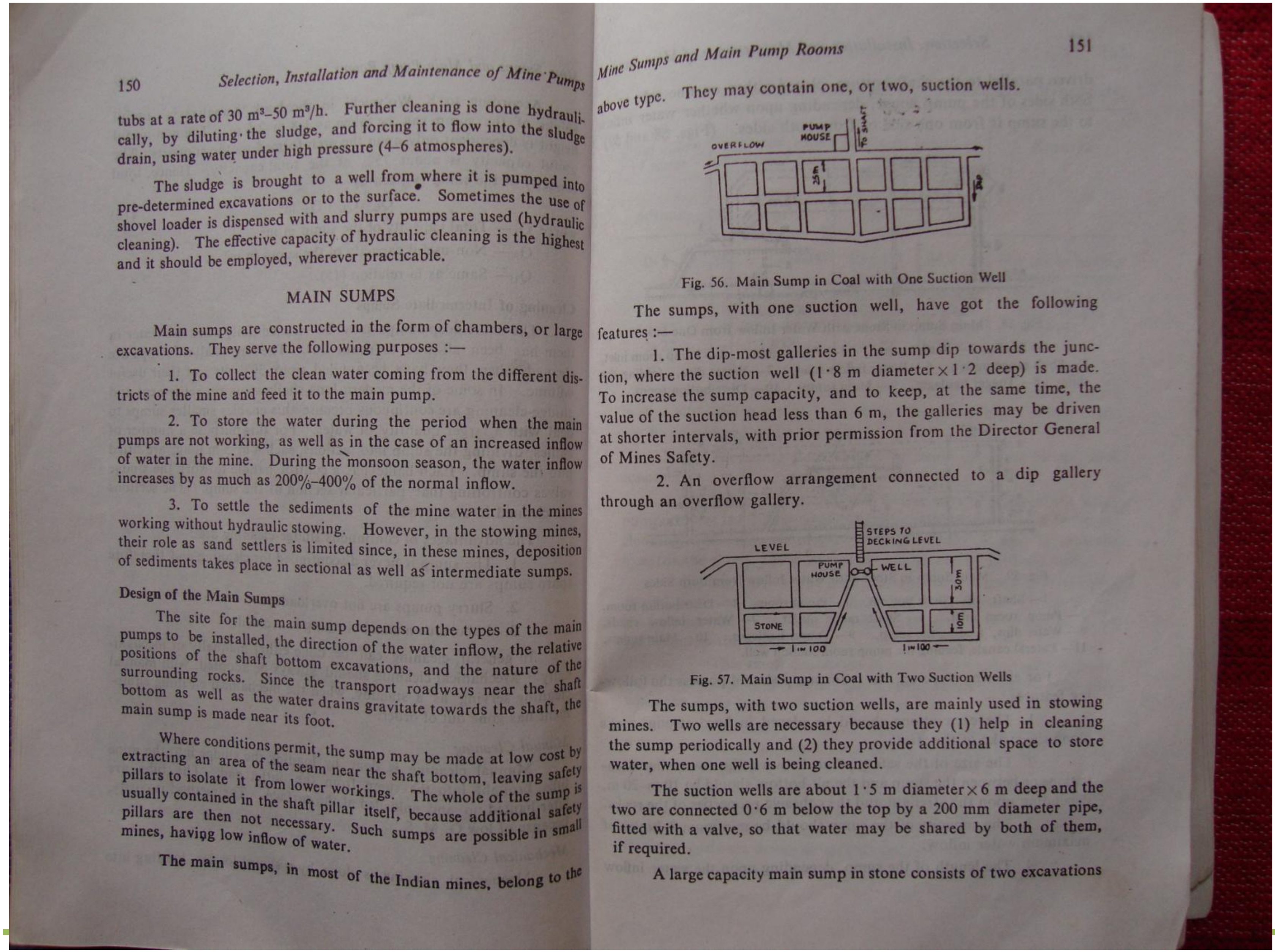
In general, cleaning can be done either manually or mechanically. Mechanical cleaning should always be adopted, with manual cleaning serving as a standby, when the mechanical cleaning equipment has gone out of order.

Manual Cleaning

Manual cleaning is done by loading the sludge into the mine tubs, brought into the sump from the outlet end. The tubs are later hauled up and unloaded at the surface. The method is costly, because of low O. M. S.

Mechanical Cleaning

Mechanical cleaning is done by a shovel loader, loading into



tubs at a rate of 30 m³–50 m³/h. Further cleaning is done hydraulically, by diluting the sludge, and forcing it to flow into the sludge drain, using water under high pressure (4–6 atmospheres).

The sludge is brought to a well from where it is pumped into pre-determined excavations or to the surface. Sometimes the use of shovel loader is dispensed with and slurry pumps are used (hydraulic cleaning). The effective capacity of hydraulic cleaning is the highest and it should be employed, wherever practicable.

MAIN SUMPS

Main sumps are constructed in the form of chambers, or large excavations. They serve the following purposes :—

1. To collect the clean water coming from the different districts of the mine and feed it to the main pump.

2. To store the water during the period when the main pumps are not working, as well as in the case of an increased inflow of water in the mine. During the monsoon season, the water inflow increases by as much as 200%–400% of the normal inflow.

3. To settle the sediments of the mine water in the mines working without hydraulic stowing. However, in the stowing mines, their role as sand settlers is limited since, in these mines, deposition of sediments takes place in sectional as well as intermediate sumps.

Design of the Main Sumps

The site for the main sump depends on the types of the main pumps to be installed, the direction of the water inflow, the relative positions of the shaft bottom excavations, and the nature of the surrounding rocks. Since the transport roadways near the shaft bottom as well as the water drains gravitate towards the shaft, the main sump is made near its foot.

Where conditions permit, the sump may be made at low cost by extracting an area of the seam near the shaft bottom, leaving safety pillars to isolate it from lower workings. The whole of the sump is usually contained in the shaft pillar itself, because additional safety pillars are then not necessary. Such sumps are possible in small mines, having low inflow of water.

The main sumps, in most of the Indian mines, belong to the

above type. They may contain one, or two, suction wells.

Fig. 56. Main Sump in Coal with One Suction Well

The sumps, with one suction well, have got the following features :—

1. The dip-most galleries in the sump dip towards the junction, where the suction well (1·8 m diameter × 1·2 deep) is made. To increase the sump capacity, and to keep, at the same time, the value of the suction head less than 6 m, the galleries may be driven at shorter intervals, with prior permission from the Director General of Mines Safety.

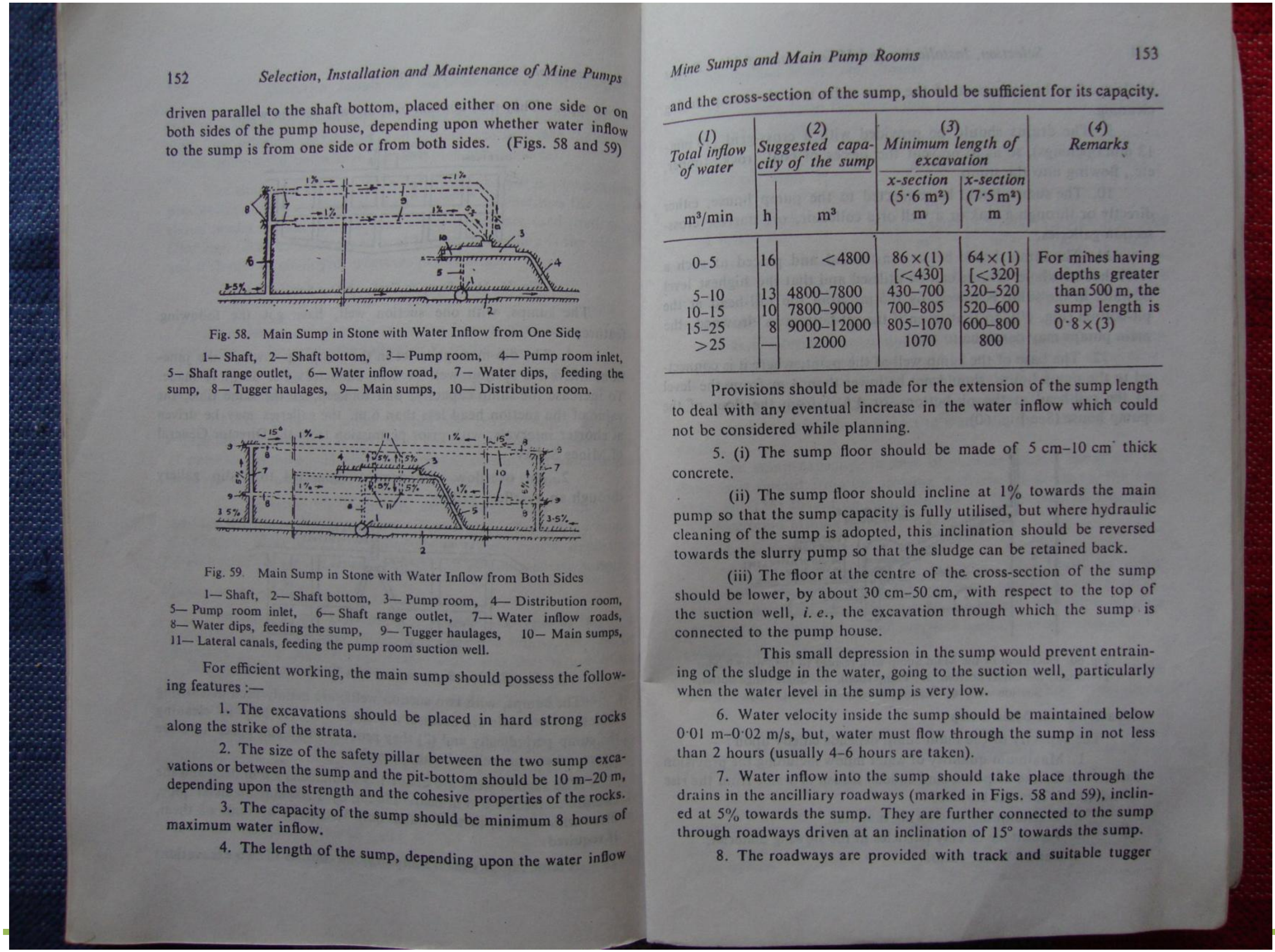
2. An overflow arrangement connected to a dip gallery through an overflow gallery.

Fig. 57. Main Sump in Coal with Two Suction Wells

The sumps, with two suction wells, are mainly used in stowing mines. Two wells are necessary because they (1) help in cleaning the sump periodically and (2) they provide additional space to store water, when one well is being cleaned.

The suction wells are about 1·5 m diameter × 6 m deep and the two are connected 0·6 m below the top by a 200 mm diameter pipe, fitted with a valve, so that water may be shared by both of them, if required.

A large capacity main sump in stone consists of two excavations



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driven parallel to the shaft bottom, placed either on one side or on both sides of the pump house, depending upon whether water inflow to the sump is from one side or from both sides. (Figs. 58 and 59)

Fig. 58. Main Sump in Stone with Water Inflow from One Side

1— Shaft, 2— Shaft bottom, 3— Pump room, 4— Pump room inlet, 5— Shaft range outlet, 6— Water inflow road, 7— Water dips, feeding the sump, 8— Tugger haulages, 9— Main sumps, 10— Distribution room.

Fig. 59. Main Sump in Stone with Water Inflow from Both Sides

1— Shaft, 2— Shaft bottom, 3— Pump room, 4— Distribution room, 5— Pump room inlet, 6— Shaft range outlet, 7— Water inflow roads, 8— Water dips, feeding the sump, 9— Tugger haulages, 10— Main sumps, 11— Lateral canals, feeding the pump room suction well.

For efficient working, the main sump should possess the following features :—

1. The excavations should be placed in hard strong rocks along the strike of the strata.

2. The size of the safety pillar between the two sump excavations or between the sump and the pit-bottom should be 10 m–20 m, depending upon the strength and the cohesive properties of the rocks.

3. The capacity of the sump should be minimum 8 hours of maximum water inflow.

4. The length of the sump, depending upon the water inflow and the cross-section of the sump, should be sufficient for its capacity.

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(1) *Total inflow of water*	*(2)* *Suggested capacity of the sump*		*(3)* *Minimum length of excavation*		*(4)* *Remarks*
			x-section (5·6 m²)	*x-section* (7·5 m²)	
m³/min	h	m³	m	m	
0–5	16	<4800	86×(1) [<430]	64×(1) [<320]	For mines having depths greater than 500 m, the sump length is 0·8×(3)
5–10	13	4800–7800	430–700	320–520	
10–15	10	7800–9000	700–805	520–600	
15–25	8	9000–12000	805–1070	600–800	
>25	—	12000	1070	800	

Provisions should be made for the extension of the sump length to deal with any eventual increase in the water inflow which could not be considered while planning.

5. (i) The sump floor should be made of 5 cm–10 cm thick concrete.

(ii) The sump floor should incline at 1% towards the main pump so that the sump capacity is fully utilised, but where hydraulic cleaning of the sump is adopted, this inclination should be reversed towards the slurry pump so that the sludge can be retained back.

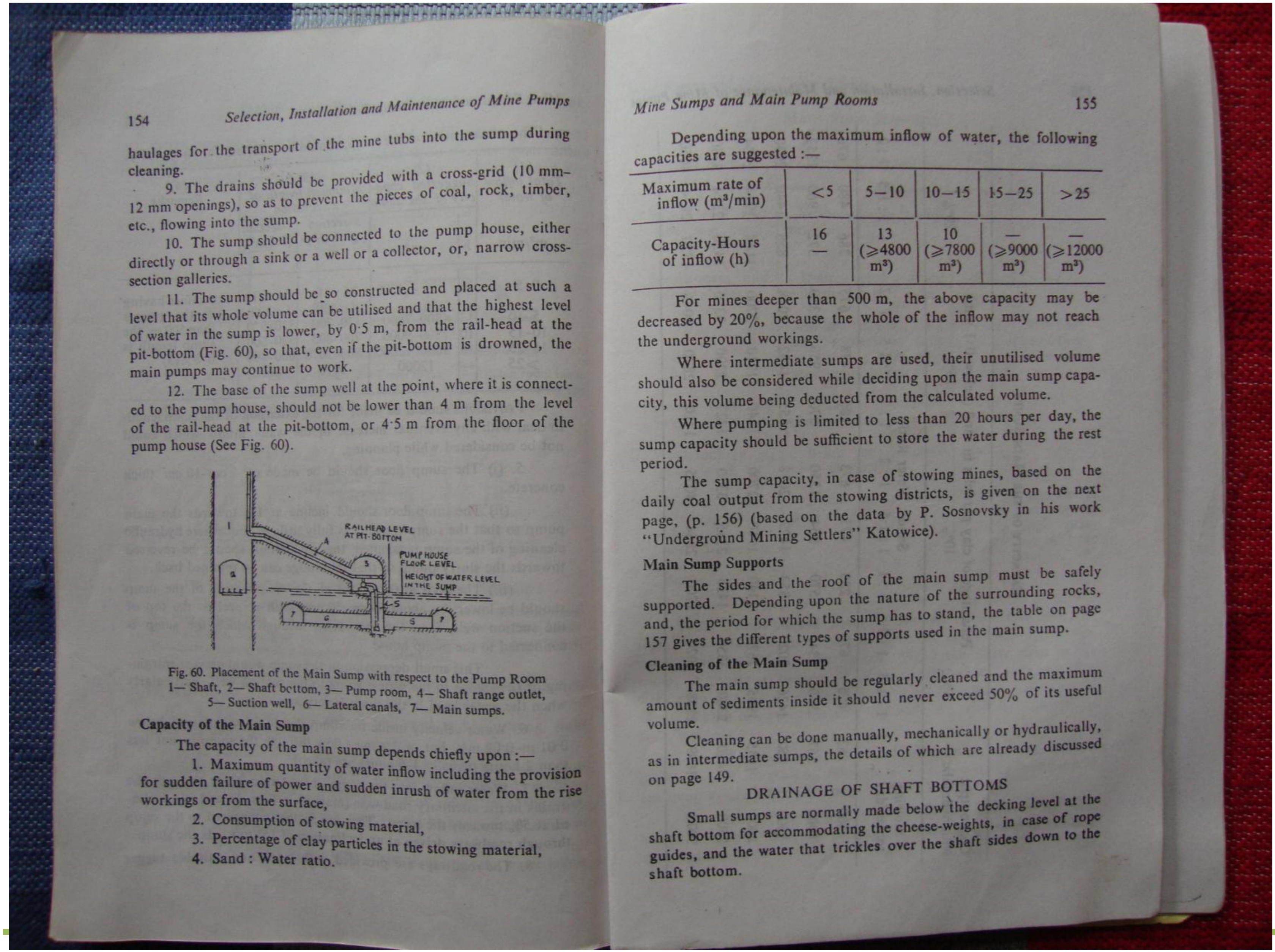
(iii) The floor at the centre of the cross-section of the sump should be lower, by about 30 cm–50 cm, with respect to the top of the suction well, *i. e.*, the excavation through which the sump is connected to the pump house.

This small depression in the sump would prevent entraining of the sludge in the water, going to the suction well, particularly when the water level in the sump is very low.

6. Water velocity inside the sump should be maintained below 0·01 m–0·02 m/s, but, water must flow through the sump in not less than 2 hours (usually 4–6 hours are taken).

7. Water inflow into the sump should take place through the drains in the ancilliary roadways (marked in Figs. 58 and 59), inclined at 5% towards the sump. They are further connected to the sump through roadways driven at an inclination of 15° towards the sump.

8. The roadways are provided with track and suitable tugger



haulages for the transport of the mine tubs into the sump during cleaning.

9. The drains should be provided with a cross-grid (10 mm–12 mm openings), so as to prevent the pieces of coal, rock, timber, etc., flowing into the sump.

10. The sump should be connected to the pump house, either directly or through a sink or a well or a collector, or, narrow cross-section galleries.

11. The sump should be so constructed and placed at such a level that its whole volume can be utilised and that the highest level of water in the sump is lower, by 0·5 m, from the rail-head at the pit-bottom (Fig. 60), so that, even if the pit-bottom is drowned, the main pumps may continue to work.

12. The base of the sump well at the point, where it is connected to the pump house, should not be lower than 4 m from the level of the rail-head at the pit-bottom, or 4·5 m from the floor of the pump house (See Fig. 60).

RAILHEAD LEVEL AT PIT-BOTTOM
PUMP HOUSE FLOOR LEVEL
HEIGHT OF WATER LEVEL IN THE SUMP
A
1
2
3
5
6
5
7
7

Fig. 60. Placement of the Main Sump with respect to the Pump Room
1— Shaft, 2— Shaft bottom, 3— Pump room, 4— Shaft range outlet,
5— Suction well, 6— Lateral canals, 7— Main sumps.

Capacity of the Main Sump

The capacity of the main sump depends chiefly upon :—

1. Maximum quantity of water inflow including the provision for sudden failure of power and sudden inrush of water from the rise workings or from the surface,
2. Consumption of stowing material,
3. Percentage of clay particles in the stowing material,
4. Sand : Water ratio.

Depending upon the maximum inflow of water, the following capacities are suggested :—

Maximum rate of inflow (m^3/min)	<5	5–10	10–15	15–25	>25
Capacity-Hours of inflow (h)	16 —	13 (⩾4800 m^3)	10 (⩾7800 m^3)	— (⩾9000 m^3)	— (⩾12000 m^3)

For mines deeper than 500 m, the above capacity may be decreased by 20%, because the whole of the inflow may not reach the underground workings.

Where intermediate sumps are used, their unutilised volume should also be considered while deciding upon the main sump capacity, this volume being deducted from the calculated volume.

Where pumping is limited to less than 20 hours per day, the sump capacity should be sufficient to store the water during the rest period.

The sump capacity, in case of stowing mines, based on the daily coal output from the stowing districts, is given on the next page, (p. 156) (based on the data by P. Sosnovsky in his work "Underground Mining Settlers" Katowice).

Main Sump Supports

The sides and the roof of the main sump must be safely supported. Depending upon the nature of the surrounding rocks, and, the period for which the sump has to stand, the table on page 157 gives the different types of supports used in the main sump.

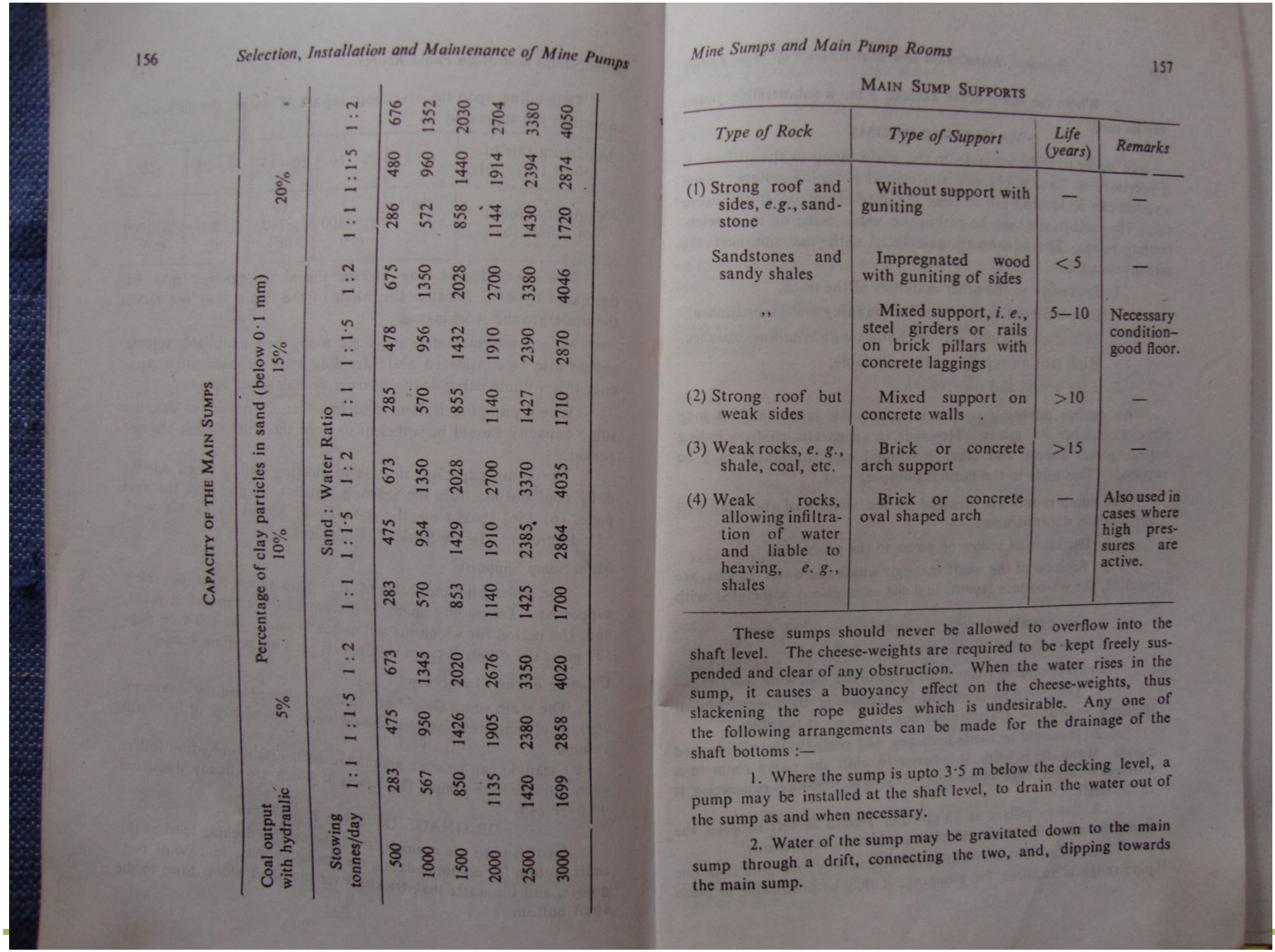
Cleaning of the Main Sump

The main sump should be regularly cleaned and the maximum amount of sediments inside it should never exceed 50% of its useful volume.

Cleaning can be done manually, mechanically or hydraulically, as in intermediate sumps, the details of which are already discussed on page 149.

DRAINAGE OF SHAFT BOTTOMS

Small sumps are normally made below the decking level at the shaft bottom for accommodating the cheese-weights, in case of rope guides, and the water that trickles over the shaft sides down to the shaft bottom.



CAPACITY OF THE MAIN SUMPS

Coal output with hydraulic Stowing tonnes/day	Percentage of clay particles in sand (below 0·1 mm)											
	5%			10%			15%			20%		
	Sand : Water Ratio											
	1 : 1	1 : 1·5	1 : 2	1 : 1	1 : 1·5	1 : 2	1 : 1	1 : 1·5	1 : 2	1 : 1	1 : 1·5	1 : 2
500	283	475	673	283	475	673	285	478	675	286	480	676
1000	567	950	1345	570	954	1350	570	956	1350	572	960	1352
1500	850	1426	2020	853	1429	2028	855	1432	2028	858	1440	2030
2000	1135	1905	2676	1140	1910	2700	1140	1910	2700	1144	1914	2704
2500	1420	2380	3350	1425	2385	3370	1427	2390	3380	1430	2394	3380
3000	1699	2858	4020	1700	2864	4035	1710	2870	4046	1720	2874	4050

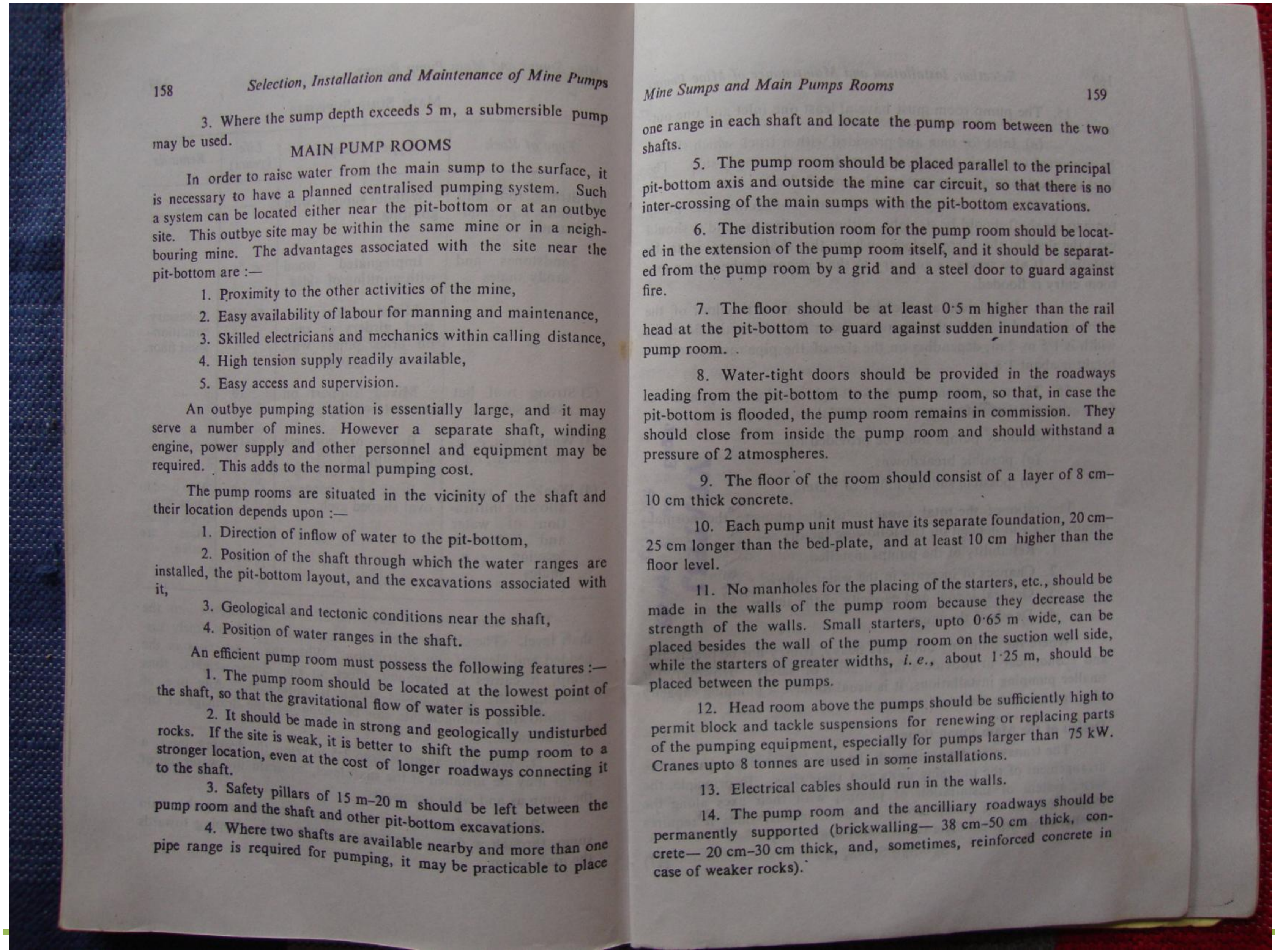
MAIN SUMP SUPPORTS

Type of Rock	*Type of Support*	*Life (years)*	*Remarks*
(1) Strong roof and sides, *e.g.*, sandstone	Without support with guniting	—	—
Sandstones and sandy shales	Impregnated wood with guniting of sides	< 5	—
,,	Mixed support, *i. e.*, steel girders or rails on brick pillars with concrete laggings	5—10	Necessary condition–good floor.
(2) Strong roof but weak sides	Mixed support on concrete walls	>10	—
(3) Weak rocks, *e. g.*, shale, coal, etc.	Brick or concrete arch support	>15	—
(4) Weak rocks, allowing infiltration of water and liable to heaving, *e. g.*, shales	Brick or concrete oval shaped arch	—	Also used in cases where high pressures are active.

These sumps should never be allowed to overflow into the shaft level. The cheese-weights are required to be kept freely suspended and clear of any obstruction. When the water rises in the sump, it causes a buoyancy effect on the cheese-weights, thus slackening the rope guides which is undesirable. Any one of the following arrangements can be made for the drainage of the shaft bottoms :—

1. Where the sump is upto 3·5 m below the decking level, a pump may be installed at the shaft level, to drain the water out of the sump as and when necessary.

2. Water of the sump may be gravitated down to the main sump through a drift, connecting the two, and, dipping towards the main sump.



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3. Where the sump depth exceeds 5 m, a submersible pump may be used.

MAIN PUMP ROOMS

In order to raise water from the main sump to the surface, it is necessary to have a planned centralised pumping system. Such a system can be located either near the pit-bottom or at an outbye site. This outbye site may be within the same mine or in a neighbouring mine. The advantages associated with the site near the pit-bottom are :—

1. Proximity to the other activities of the mine,
2. Easy availability of labour for manning and maintenance,
3. Skilled electricians and mechanics within calling distance,
4. High tension supply readily available,
5. Easy access and supervision.

An outbye pumping station is essentially large, and it may serve a number of mines. However a separate shaft, winding engine, power supply and other personnel and equipment may be required. This adds to the normal pumping cost.

The pump rooms are situated in the vicinity of the shaft and their location depends upon :—

1. Direction of inflow of water to the pit-bottom,
2. Position of the shaft through which the water ranges are installed, the pit-bottom layout, and the excavations associated with it,
3. Geological and tectonic conditions near the shaft,
4. Position of water ranges in the shaft.

An efficient pump room must possess the following features :—

1. The pump room should be located at the lowest point of the shaft, so that the gravitational flow of water is possible.

2. It should be made in strong and geologically undisturbed rocks. If the site is weak, it is better to shift the pump room to a stronger location, even at the cost of longer roadways connecting it to the shaft.

3. Safety pillars of 15 m–20 m should be left between the pump room and the shaft and other pit-bottom excavations.

4. Where two shafts are available nearby and more than one pipe range is required for pumping, it may be practicable to place one range in each shaft and locate the pump room between the two shafts.

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5. The pump room should be placed parallel to the principal pit-bottom axis and outside the mine car circuit, so that there is no inter-crossing of the main sumps with the pit-bottom excavations.

6. The distribution room for the pump room should be located in the extension of the pump room itself, and it should be separated from the pump room by a grid and a steel door to guard against fire.

7. The floor should be at least 0·5 m higher than the rail head at the pit-bottom to guard against sudden inundation of the pump room.

8. Water-tight doors should be provided in the roadways leading from the pit-bottom to the pump room, so that, in case the pit-bottom is flooded, the pump room remains in commission. They should close from inside the pump room and should withstand a pressure of 2 atmospheres.

9. The floor of the room should consist of a layer of 8 cm–10 cm thick concrete.

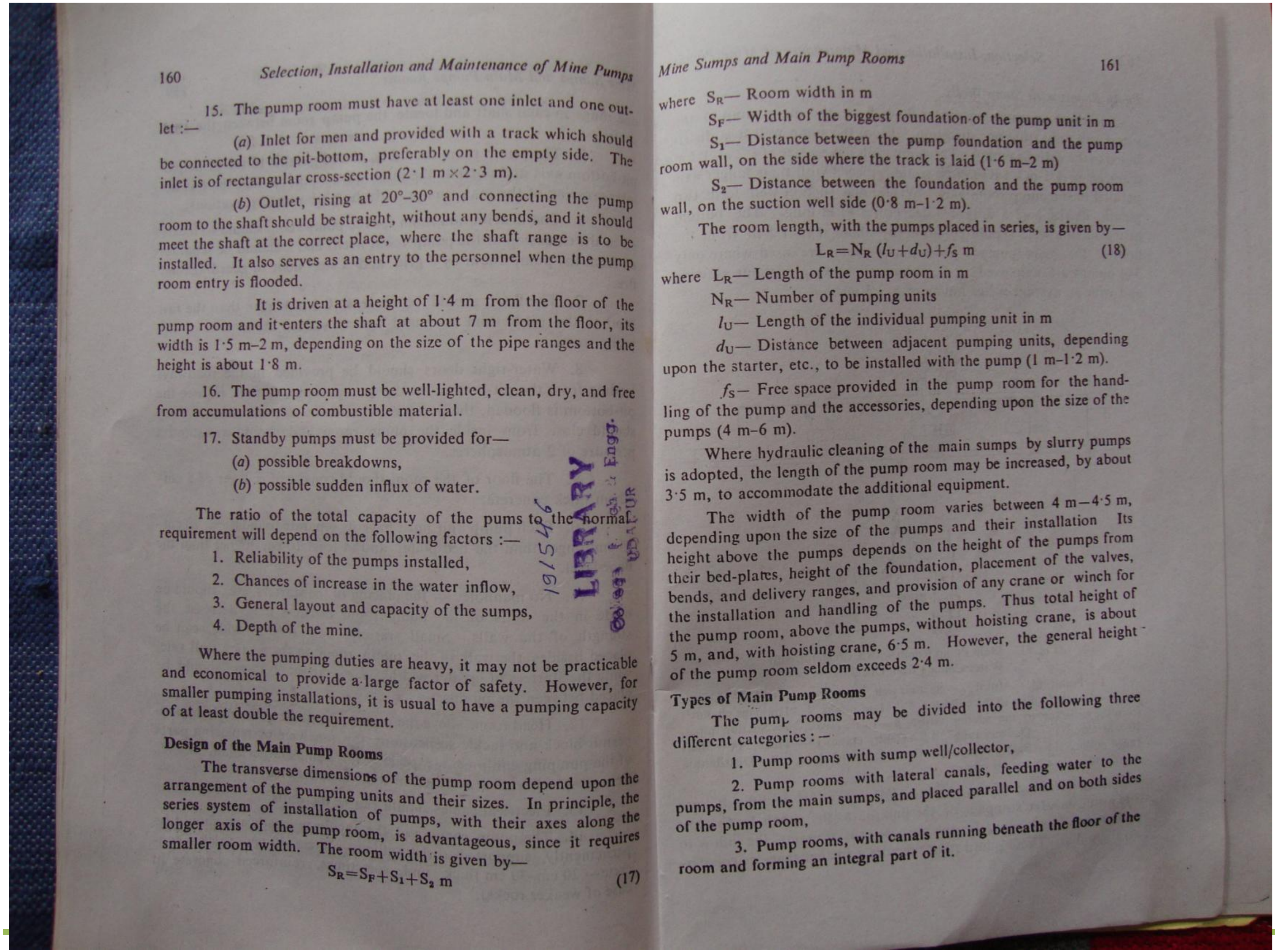
10. Each pump unit must have its separate foundation, 20 cm–25 cm longer than the bed-plate, and at least 10 cm higher than the floor level.

11. No manholes for the placing of the starters, etc., should be made in the walls of the pump room because they decrease the strength of the walls. Small starters, upto 0·65 m wide, can be placed besides the wall of the pump room on the suction well side, while the starters of greater widths, *i. e.*, about 1·25 m, should be placed between the pumps.

12. Head room above the pumps should be sufficiently high to permit block and tackle suspensions for renewing or replacing parts of the pumping equipment, especially for pumps larger than 75 kW. Cranes upto 8 tonnes are used in some installations.

13. Electrical cables should run in the walls.

14. The pump room and the ancilliary roadways should be permanently supported (brickwalling— 38 cm–50 cm thick, concrete— 20 cm–30 cm thick, and, sometimes, reinforced concrete in case of weaker rocks).



15. The pump room must have at least one inlet and one outlet :—

(*a*) Inlet for men and provided with a track which should be connected to the pit-bottom, preferably on the empty side. The inlet is of rectangular cross-section (2·1 m × 2·3 m).

(*b*) Outlet, rising at 20°–30° and connecting the pump room to the shaft should be straight, without any bends, and it should meet the shaft at the correct place, where the shaft range is to be installed. It also serves as an entry to the personnel when the pump room entry is flooded.

It is driven at a height of 1·4 m from the floor of the pump room and it enters the shaft at about 7 m from the floor, its width is 1·5 m–2 m, depending on the size of the pipe ranges and the height is about 1·8 m.

16. The pump room must be well-lighted, clean, dry, and free from accumulations of combustible material.

17. Standby pumps must be provided for—

(*a*) possible breakdowns,

(*b*) possible sudden influx of water.

The ratio of the total capacity of the pums to the normal requirement will depend on the following factors :—

1. Reliability of the pumps installed,
2. Chances of increase in the water inflow,
3. General layout and capacity of the sumps,
4. Depth of the mine.

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Where the pumping duties are heavy, it may not be practicable and economical to provide a large factor of safety. However, for smaller pumping installations, it is usual to have a pumping capacity of at least double the requirement.

Design of the Main Pump Rooms

The transverse dimensions of the pump room depend upon the arrangement of the pumping units and their sizes. In principle, the series system of installation of pumps, with their axes along the longer axis of the pump room, is advantageous, since it requires smaller room width. The room width is given by—

$$S_R = S_F + S_1 + S_2 \text{ m} \qquad (17)$$

where S_R— Room width in m

S_F— Width of the biggest foundation of the pump unit in m

S_1— Distance between the pump foundation and the pump room wall, on the side where the track is laid (1·6 m–2 m)

S_2— Distance between the foundation and the pump room wall, on the suction well side (0·8 m–1·2 m).

The room length, with the pumps placed in series, is given by—

$$L_R = N_R\,(l_U + d_U) + f_S \text{ m} \qquad (18)$$

where L_R— Length of the pump room in m

N_R— Number of pumping units

l_U— Length of the individual pumping unit in m

d_U— Distance between adjacent pumping units, depending upon the starter, etc., to be installed with the pump (1 m–1·2 m).

f_S— Free space provided in the pump room for the handling of the pump and the accessories, depending upon the size of the pumps (4 m–6 m).

Where hydraulic cleaning of the main sumps by slurry pumps is adopted, the length of the pump room may be increased, by about 3·5 m, to accommodate the additional equipment.

The width of the pump room varies between 4 m—4·5 m, depending upon the size of the pumps and their installation Its height above the pumps depends on the height of the pumps from their bed-plates, height of the foundation, placement of the valves, bends, and delivery ranges, and provision of any crane or winch for the installation and handling of the pumps. Thus total height of the pump room, above the pumps, without hoisting crane, is about 5 m, and, with hoisting crane, 6·5 m. However, the general height of the pump room seldom exceeds 2·4 m.

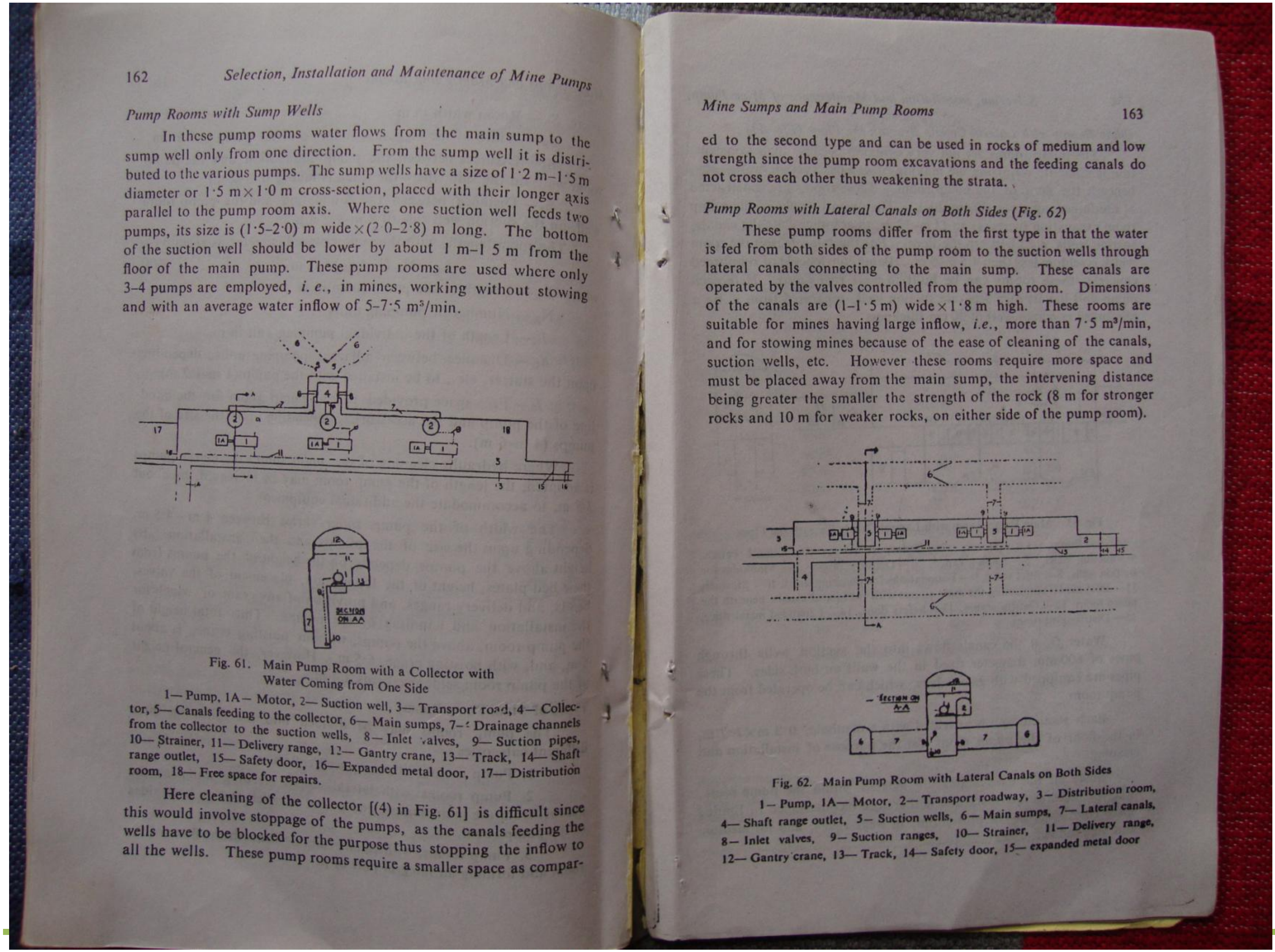
Types of Main Pump Rooms

The pump rooms may be divided into the following three different categories :—

1. Pump rooms with sump well/collector,

2. Pump rooms with lateral canals, feeding water to the pumps, from the main sumps, and placed parallel and on both sides of the pump room,

3. Pump rooms, with canals running beneath the floor of the room and forming an integral part of it.



Pump Rooms with Sump Wells

In these pump rooms water flows from the main sump to the sump well only from one direction. From the sump well it is distributed to the various pumps. The sump wells have a size of 1·2 m–1·5 m diameter or 1·5 m × 1·0 m cross-section, placed with their longer axis parallel to the pump room axis. Where one suction well feeds two pumps, its size is (1·5–2·0) m wide × (2 0–2·8) m long. The bottom of the suction well should be lower by about 1 m–1 5 m from the floor of the main pump. These pump rooms are used where only 3-4 pumps are employed, *i. e.*, in mines, working without stowing and with an average water inflow of 5–7·5 m^3/min.

Fig. 61. Main Pump Room with a Collector with Water Coming from One Side

1— Pump, 1A— Motor, 2— Suction well, 3— Transport road, 4— Collector, 5— Canals feeding to the collector, 6— Main sumps, 7— Drainage channels from the collector to the suction wells, 8— Inlet valves, 9— Suction pipes, 10— Strainer, 11— Delivery range, 12— Gantry crane, 13— Track, 14— Shaft range outlet, 15— Safety door, 16— Expanded metal door, 17— Distribution room, 18— Free space for repairs.

Here cleaning of the collector [(4) in Fig. 61] is difficult since this would involve stoppage of the pumps, as the canals feeding the wells have to be blocked for the purpose thus stopping the inflow to all the wells. These pump rooms require a smaller space as compar-

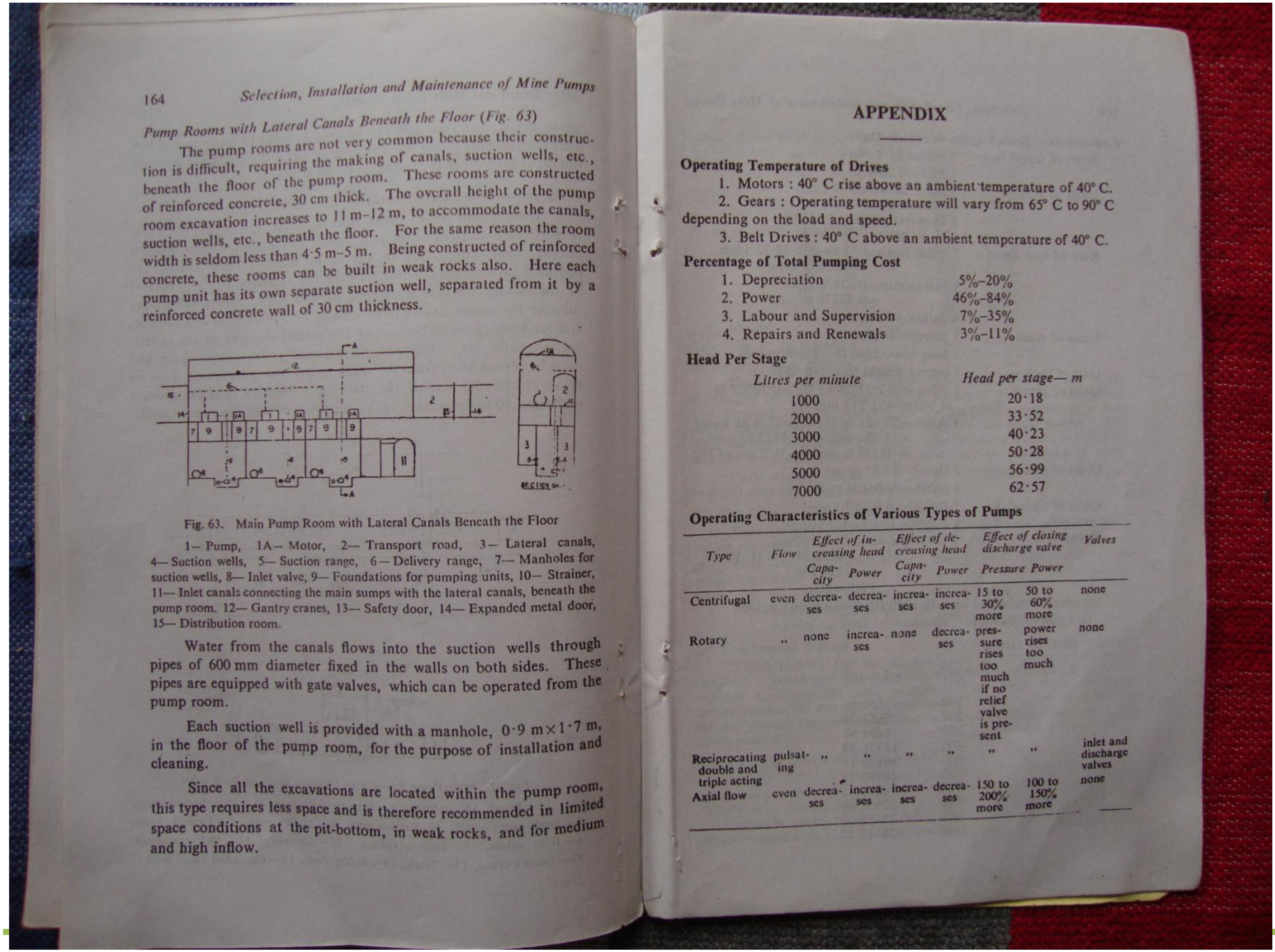
ed to the second type and can be used in rocks of medium and low strength since the pump room excavations and the feeding canals do not cross each other thus weakening the strata.

Pump Rooms with Lateral Canals on Both Sides (Fig. 62)

These pump rooms differ from the first type in that the water is fed from both sides of the pump room to the suction wells through lateral canals connecting to the main sump. These canals are operated by the valves controlled from the pump room. Dimensions of the canals are (1–1·5 m) wide × 1·8 m high. These rooms are suitable for mines having large inflow, *i.e.*, more than 7·5 m^3/min, and for stowing mines because of the ease of cleaning of the canals, suction wells, etc. However these rooms require more space and must be placed away from the main sump, the intervening distance being greater the smaller the strength of the rock (8 m for stronger rocks and 10 m for weaker rocks, on either side of the pump room).

Fig. 62. Main Pump Room with Lateral Canals on Both Sides

1— Pump, 1A— Motor, 2— Transport roadway, 3— Distribution room, 4— Shaft range outlet, 5— Suction wells, 6— Main sumps, 7— Lateral canals, 8— Inlet valves, 9— Suction ranges, 10— Strainer, 11— Delivery range, 12— Gantry crane, 13— Track, 14— Safety door, 15— expanded metal door



Pump Rooms with Lateral Canals Beneath the Floor (Fig. 63)

The pump rooms are not very common because their construction is difficult, requiring the making of canals, suction wells, etc., beneath the floor of the pump room. These rooms are constructed of reinforced concrete, 30 cm thick. The overall height of the pump room excavation increases to 11 m–12 m, to accommodate the canals, suction wells, etc., beneath the floor. For the same reason the room width is seldom less than 4·5 m–5 m. Being constructed of reinforced concrete, these rooms can be built in weak rocks also. Here each pump unit has its own separate suction well, separated from it by a reinforced concrete wall of 30 cm thickness.

Fig. 63. Main Pump Room with Lateral Canals Beneath the Floor

1– Pump, 1A– Motor, 2– Transport road, 3– Lateral canals, 4– Suction wells, 5– Suction range, 6– Delivery range, 7– Manholes for suction wells, 8– Inlet valve, 9– Foundations for pumping units, 10– Strainer, 11– Inlet canals connecting the main sumps with the lateral canals, beneath the pump room, 12– Gantry cranes, 13– Safety door, 14– Expanded metal door, 15– Distribution room.

Water from the canals flows into the suction wells through pipes of 600 mm diameter fixed in the walls on both sides. These pipes are equipped with gate valves, which can be operated from the pump room.

Each suction well is provided with a manhole, 0·9 m × 1·7 m, in the floor of the pump room, for the purpose of installation and cleaning.

Since all the excavations are located within the pump room, this type requires less space and is therefore recommended for limited space conditions at the pit-bottom, in weak rocks, and for medium and high inflow.

APPENDIX

Operating Temperature of Drives

1. Motors : 40° C rise above an ambient temperature of 40° C.
2. Gears : Operating temperature will vary from 65° C to 90° C depending on the load and speed.
3. Belt Drives : 40° C above an ambient temperature of 40° C.

Percentage of Total Pumping Cost

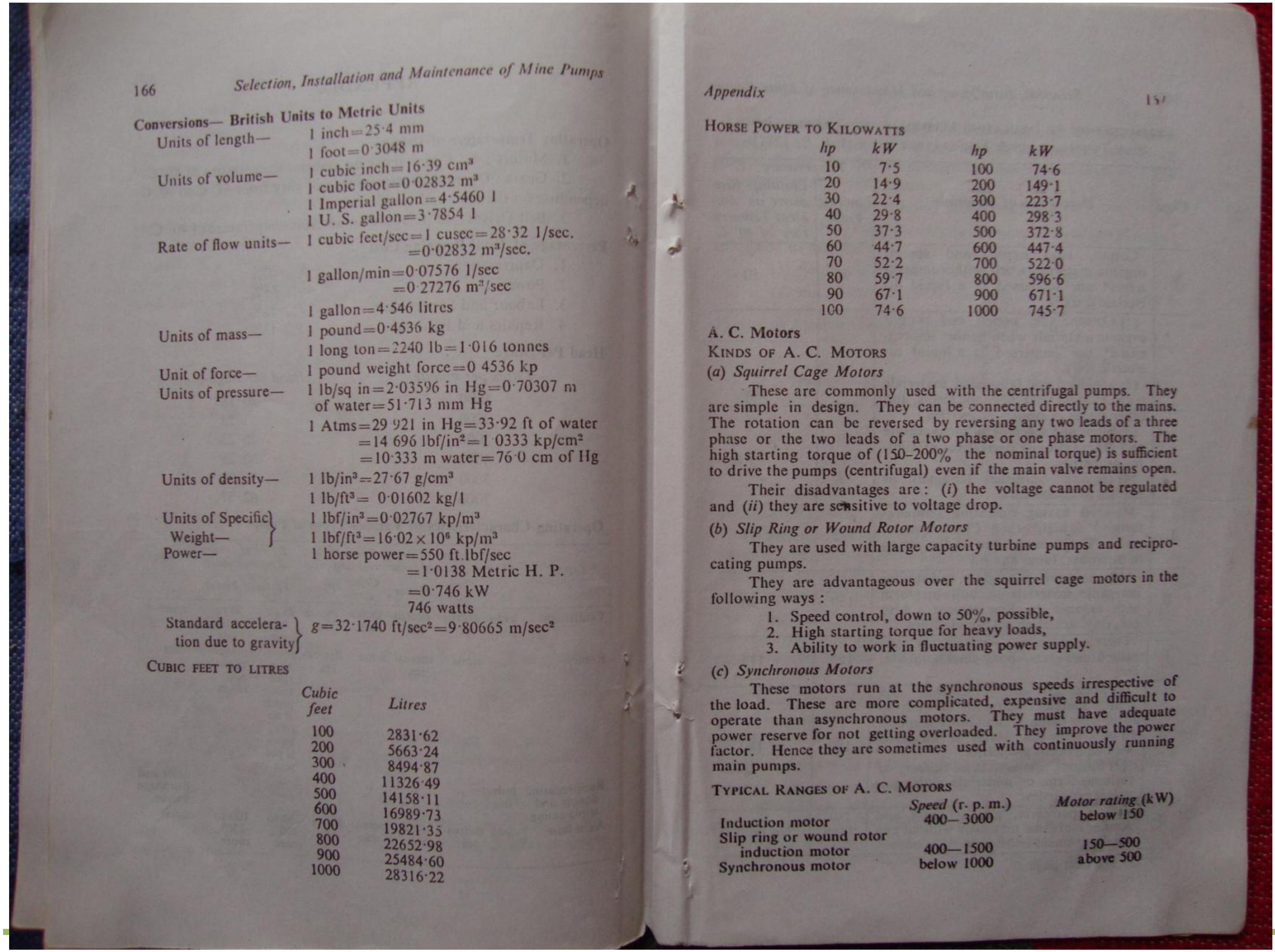
1. Depreciation	5%–20%
2. Power	46%–84%
3. Labour and Supervision	7%–35%
4. Repairs and Renewals	3%–11%

Head Per Stage

Litres per minute	*Head per stage— m*
1000	20·18
2000	33·52
3000	40·23
4000	50·28
5000	56·99
7000	62·57

Operating Characteristics of Various Types of Pumps

Type	*Flow*	*Effect of increasing head*		*Effect of decreasing head*		*Effect of closing discharge valve*		*Valves*
		Capacity	*Power*	*Capacity*	*Power*	*Pressure*	*Power*	
Centrifugal	even	decreases	decreases	increases	increases	15 to 30% more	50 to 60% more	none
Rotary	,,	none	increases	none	decreases	pressure rises too much if no relief valve is present	power rises too much	none
Reciprocating double and triple acting	pulsating	,,	,,	,,	,,	,,	,,	inlet and discharge valves
Axial flow	even	decreases	increases	increases	decreases	150 to 200% more	100 to 150% more	none



Conversions— British Units to Metric Units

Units of length— 1 inch=25·4 mm
1 foot=0·3048 m
Units of volume— 1 cubic inch=16·39 cm^3
1 cubic foot=0·02832 m^3
1 Imperial gallon=4·5460 l
1 U. S. gallon=3·7854 l
Rate of flow units— 1 cubic feet/sec=1 cusec=28·32 l/sec.
=0·02832 m^3/sec.
1 gallon/min=0·07576 l/sec
=0·27276 m^3/sec
1 gallon=4·546 litres
Units of mass— 1 pound=0·4536 kg
1 long ton=2240 lb=1·016 tonnes
Unit of force— 1 pound weight force=0 4536 kp
Units of pressure— 1 lb/sq in=2·03596 in Hg=0·70307 m of water=51·713 mm Hg
1 Atms=29 921 in Hg=33·92 ft of water
=14 696 lbf/in^2=1 0333 kp/cm^2
=10·333 m water=76·0 cm of Hg
Units of density— 1 lb/in^3=27·67 g/cm^3
1 lb/ft^3= 0·01602 kg/l
Units of Specific Weight— 1 lbf/in^3=0·02767 kp/m^3
1 lbf/ft^3=16·02 × 10^6 kp/m^3
Power— 1 horse power=550 ft.lbf/sec
=1·0138 Metric H. P.
=0·746 kW
746 watts
Standard acceleration due to gravity g=32·1740 ft/sec^2=9·80665 m/sec^2

CUBIC FEET TO LITRES

Cubic feet	*Litres*
100	2831·62
200	5663·24
300	8494·87
400	11326·49
500	14158·11
600	16989·73
700	19821·35
800	22652·98
900	25484·60
1000	28316·22

HORSE POWER TO KILOWATTS

hp	*kW*	*hp*	*kW*
10	7·5	100	74·6
20	14·9	200	149·1
30	22·4	300	223·7
40	29·8	400	298·3
50	37·3	500	372·8
60	44·7	600	447·4
70	52·2	700	522·0
80	59·7	800	596·6
90	67·1	900	671·1
100	74·6	1000	745·7

A. C. Motors

KINDS OF A. C. MOTORS

(a) *Squirrel Cage Motors*

These are commonly used with the centrifugal pumps. They are simple in design. They can be connected directly to the mains. The rotation can be reversed by reversing any two leads of a three phase or the two leads of a two phase or one phase motors. The high starting torque of (150–200% the nominal torque) is sufficient to drive the pumps (centrifugal) even if the main valve remains open.

Their disadvantages are: (*i*) the voltage cannot be regulated and (*ii*) they are sensitive to voltage drop.

(b) *Slip Ring or Wound Rotor Motors*

They are used with large capacity turbine pumps and reciprocating pumps.

They are advantageous over the squirrel cage motors in the following ways :

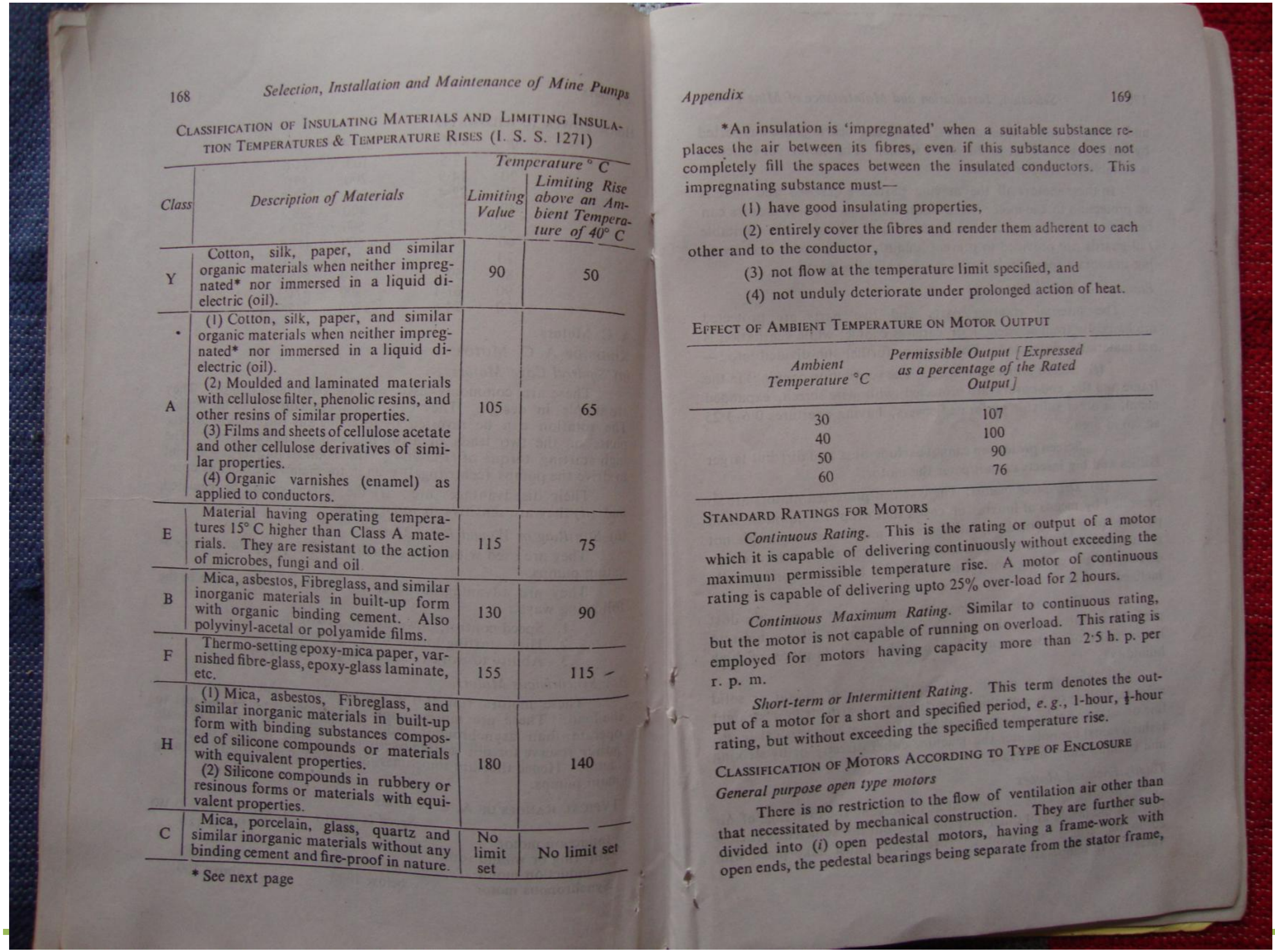
1. Speed control, down to 50%, possible,
2. High starting torque for heavy loads,
3. Ability to work in fluctuating power supply.

(c) *Synchronous Motors*

These motors run at the synchronous speeds irrespective of the load. These are more complicated, expensive and difficult to operate than asynchronous motors. They must have adequate power reserve for not getting overloaded. They improve the power factor. Hence they are sometimes used with continuously running main pumps.

TYPICAL RANGES OF A. C. MOTORS

	Speed (r. p. m.)	*Motor rating* (kW)
Induction motor	400—3000	below 150
Slip ring or wound rotor induction motor	400—1500	150—500
Synchronous motor	below 1000	above 500



CLASSIFICATION OF INSULATING MATERIALS AND LIMITING INSULATION TEMPERATURES & TEMPERATURE RISES (I. S. S. 1271)

Class	*Description of Materials*	*Temperature ° C*	
		Limiting Value	*Limiting Rise above an Ambient Temperature of 40° C*
Y	Cotton, silk, paper, and similar organic materials when neither impregnated* nor immersed in a liquid dielectric (oil).	90	50
A	(1) Cotton, silk, paper, and similar organic materials when neither impregnated* nor immersed in a liquid dielectric (oil). (2) Moulded and laminated materials with cellulose filter, phenolic resins, and other resins of similar properties. (3) Films and sheets of cellulose acetate and other cellulose derivatives of similar properties. (4) Organic varnishes (enamel) as applied to conductors.	105	65
E	Material having operating temperatures 15° C higher than Class A materials. They are resistant to the action of microbes, fungi and oil	115	75
B	Mica, asbestos, Fibreglass, and similar inorganic materials in built-up form with organic binding cement. Also polyvinyl-acetal or polyamide films.	130	90
F	Thermo-setting epoxy-mica paper, varnished fibre-glass, epoxy-glass laminate, etc.	155	115
H	(1) Mica, asbestos, Fibreglass, and similar inorganic materials in built-up form with binding substances composed of silicone compounds or materials with equivalent properties. (2) Silicone compounds in rubbery or resinous forms or materials with equivalent properties.	180	140
C	Mica, porcelain, glass, quartz and similar inorganic materials without any binding cement and fire-proof in nature.	No limit set	No limit set

* See next page

*An insulation is 'impregnated' when a suitable substance replaces the air between its fibres, even if this substance does not completely fill the spaces between the insulated conductors. This impregnating substance must—

(1) have good insulating properties,

(2) entirely cover the fibres and render them adherent to each other and to the conductor,

(3) not flow at the temperature limit specified, and

(4) not unduly deteriorate under prolonged action of heat.

EFFECT OF AMBIENT TEMPERATURE ON MOTOR OUTPUT

Ambient Temperature °C	*Permissible Output [Expressed as a percentage of the Rated Output]*
30	107
40	100
50	90
60	76

STANDARD RATINGS FOR MOTORS

Continuous Rating. This is the rating or output of a motor which it is capable of delivering continuously without exceeding the maximum permissible temperature rise. A motor of continuous rating is capable of delivering upto 25% over-load for 2 hours.

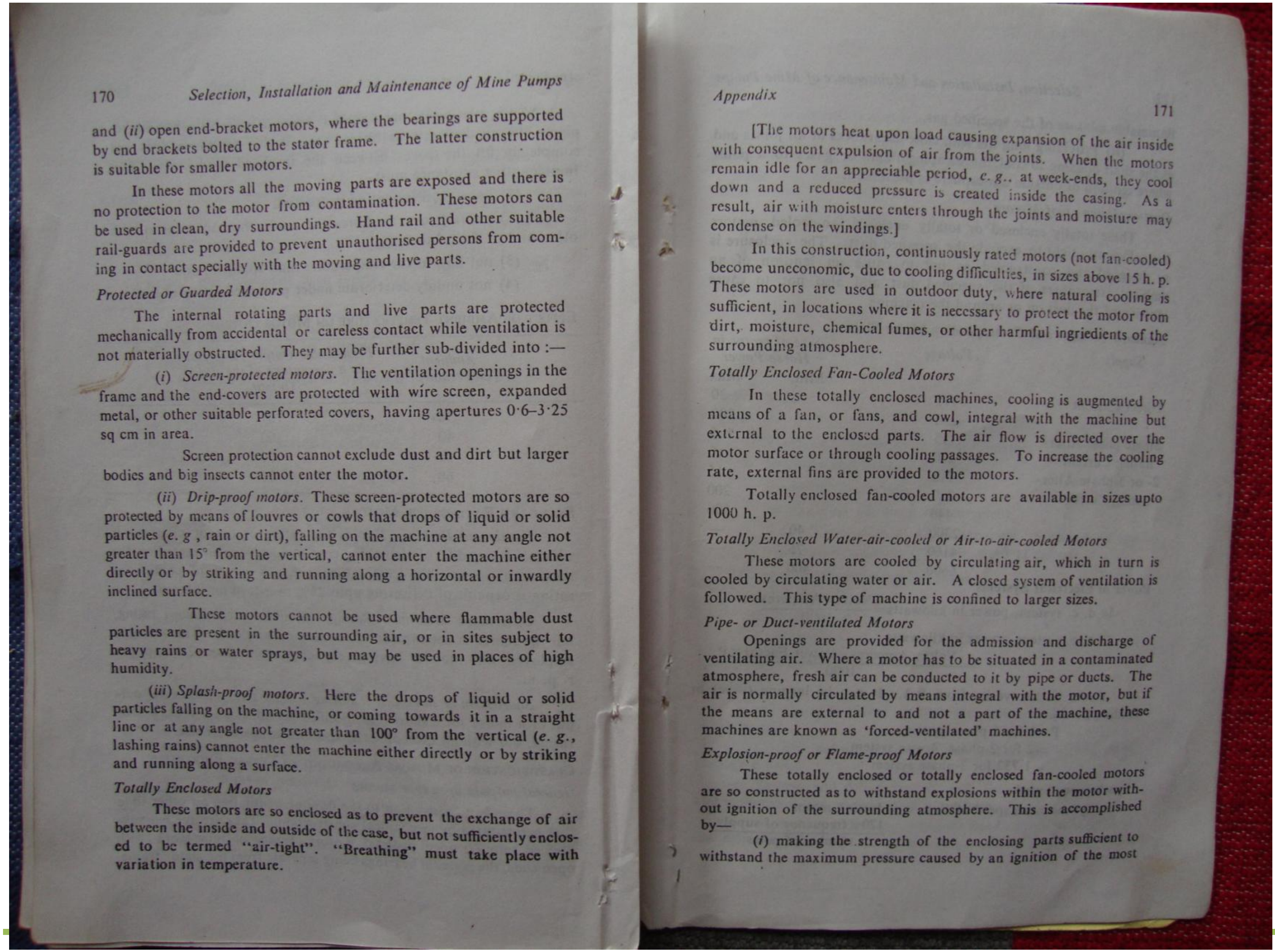
Continuous Maximum Rating. Similar to continuous rating, but the motor is not capable of running on overload. This rating is employed for motors having capacity more than 2·5 h. p. per r. p. m.

Short-term or Intermittent Rating. This term denotes the output of a motor for a short and specified period, *e. g.*, 1-hour, ½-hour rating, but without exceeding the specified temperature rise.

CLASSIFICATION OF MOTORS ACCORDING TO TYPE OF ENCLOSURE

General purpose open type motors

There is no restriction to the flow of ventilation air other than that necessitated by mechanical construction. They are further subdivided into (*i*) open pedestal motors, having a frame-work with open ends, the pedestal bearings being separate from the stator frame,



and (*ii*) open end-bracket motors, where the bearings are supported by end brackets bolted to the stator frame. The latter construction is suitable for smaller motors.

In these motors all the moving parts are exposed and there is no protection to the motor from contamination. These motors can be used in clean, dry surroundings. Hand rail and other suitable rail-guards are provided to prevent unauthorised persons from coming in contact specially with the moving and live parts.

Protected or Guarded Motors

The internal rotating parts and live parts are protected mechanically from accidental or careless contact while ventilation is not materially obstructed. They may be further sub-divided into :—

(*i*) *Screen-protected motors*. The ventilation openings in the frame and the end-covers are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures 0·6–3·25 sq cm in area.

Screen protection cannot exclude dust and dirt but larger bodies and big insects cannot enter the motor.

(*ii*) *Drip-proof motors*. These screen-protected motors are so protected by means of louvres or cowls that drops of liquid or solid particles (*e. g* , rain or dirt), falling on the machine at any angle not greater than 15° from the vertical, cannot enter the machine either directly or by striking and running along a horizontal or inwardly inclined surface.

These motors cannot be used where flammable dust particles are present in the surrounding air, or in sites subject to heavy rains or water sprays, but may be used in places of high humidity.

(*iii*) *Splash-proof motors*. Here the drops of liquid or solid particles falling on the machine, or coming towards it in a straight line or at any angle not greater than 100° from the vertical (*e. g.*, lashing rains) cannot enter the machine either directly or by striking and running along a surface.

Totally Enclosed Motors

These motors are so enclosed as to prevent the exchange of air between the inside and outside of the case, but not sufficiently enclosed to be termed "air-tight". "Breathing" must take place with variation in temperature.

[The motors heat upon load causing expansion of the air inside with consequent expulsion of air from the joints. When the motors remain idle for an appreciable period, *e. g.*, at week-ends, they cool down and a reduced pressure is created inside the casing. As a result, air with moisture enters through the joints and moisture may condense on the windings.]

In this construction, continuously rated motors (not fan-cooled) become uneconomic, due to cooling difficulties, in sizes above 15 h. p. These motors are used in outdoor duty, where natural cooling is sufficient, in locations where it is necessary to protect the motor from dirt, moisture, chemical fumes, or other harmful ingriedients of the surrounding atmosphere.

Totally Enclosed Fan-Cooled Motors

In these totally enclosed machines, cooling is augmented by means of a fan, or fans, and cowl, integral with the machine but external to the enclosed parts. The air flow is directed over the motor surface or through cooling passages. To increase the cooling rate, external fins are provided to the motors.

Totally enclosed fan-cooled motors are available in sizes upto 1000 h. p.

Totally Enclosed Water-air-cooled or Air-to-air-cooled Motors

These motors are cooled by circulating air, which in turn is cooled by circulating water or air. A closed system of ventilation is followed. This type of machine is confined to larger sizes.

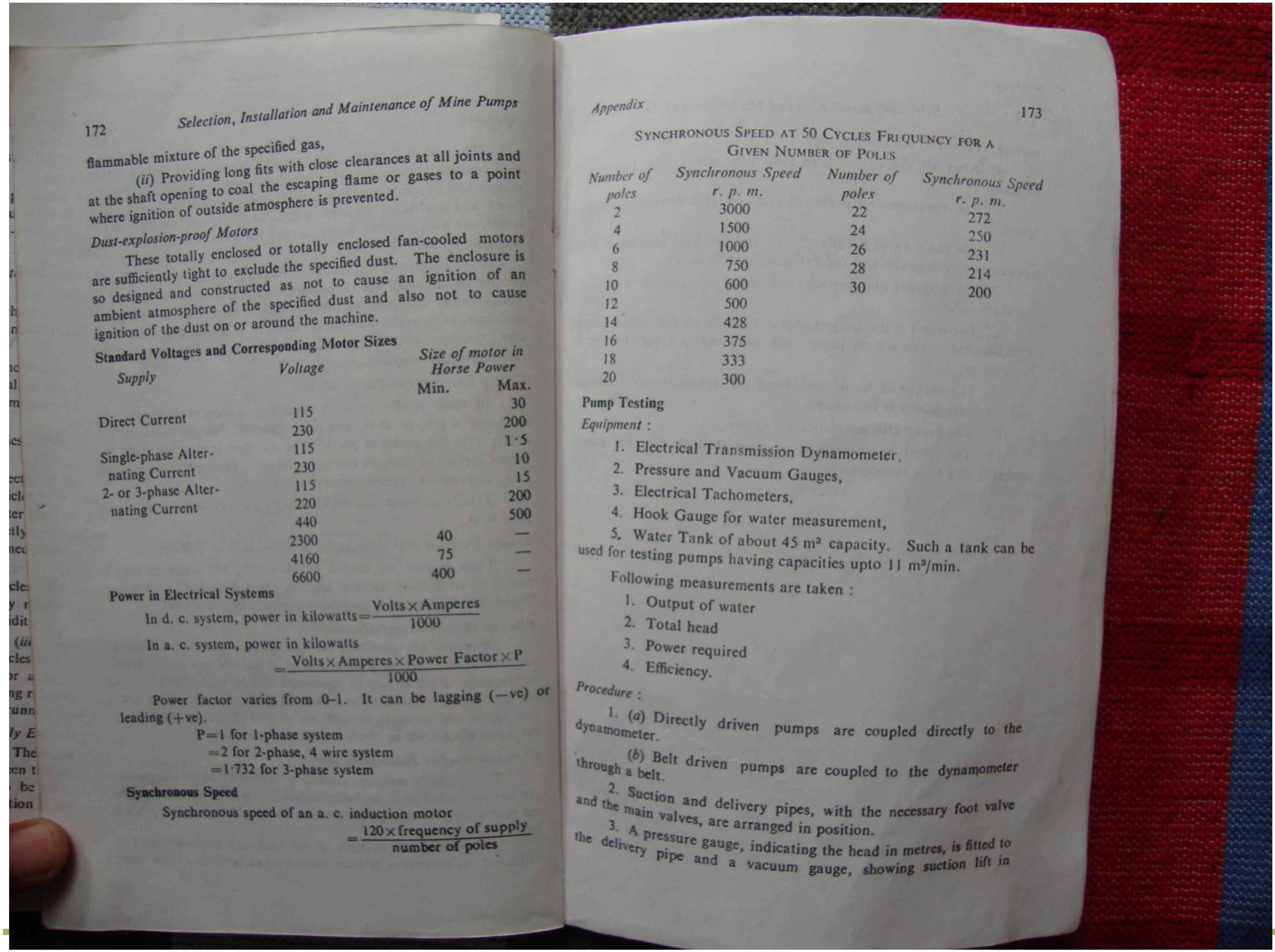
Pipe- or Duct-ventilated Motors

Openings are provided for the admission and discharge of ventilating air. Where a motor has to be situated in a contaminated atmosphere, fresh air can be conducted to it by pipe or ducts. The air is normally circulated by means integral with the motor, but if the means are external to and not a part of the machine, these machines are known as 'forced-ventilated' machines.

Explosion-proof or Flame-proof Motors

These totally enclosed or totally enclosed fan-cooled motors are so constructed as to withstand explosions within the motor without ignition of the surrounding atmosphere. This is accomplished by—

(*i*) making the strength of the enclosing parts sufficient to withstand the maximum pressure caused by an ignition of the most



flammable mixture of the specified gas,

(*ii*) Providing long fits with close clearances at all joints and at the shaft opening to coal the escaping flame or gases to a point where ignition of outside atmosphere is prevented.

Dust-explosion-proof Motors

These totally enclosed or totally enclosed fan-cooled motors are sufficiently tight to exclude the specified dust. The enclosure is so designed and constructed as not to cause an ignition of an ambient atmosphere of the specified dust and also not to cause ignition of the dust on or around the machine.

Standard Voltages and Corresponding Motor Sizes

Supply	*Voltage*	*Size of motor in Horse Power* Min.	Max.
Direct Current	115		30
	230		200
Single-phase Alternating Current	115		1·5
	230		10
2- or 3-phase Alternating Current	115		15
	220		200
	440		500
	2300	40	—
	4160	75	—
	6600	400	—

Power in Electrical Systems

In d. c. system, power in kilowatts $= \dfrac{\text{Volts} \times \text{Amperes}}{1000}$

In a. c. system, power in kilowatts

$$= \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times \text{P}}{1000}$$

Power factor varies from 0–1. It can be lagging (–ve) or leading (+ve).

P=1 for 1-phase system
=2 for 2-phase, 4 wire system
=1·732 for 3-phase system

Synchronous Speed

Synchronous speed of an a. c. induction motor

$$= \frac{120 \times \text{frequency of supply}}{\text{number of poles}}$$

SYNCHRONOUS SPEED AT 50 CYCLES FREQUENCY FOR A GIVEN NUMBER OF POLES

Number of poles	*Synchronous Speed r. p. m.*	*Number of poles*	*Synchronous Speed r. p. m.*
2	3000	22	272
4	1500	24	250
6	1000	26	231
8	750	28	214
10	600	30	200
12	500		
14	428		
16	375		
18	333		
20	300		

Pump Testing

Equipment :

1. Electrical Transmission Dynamometer,
2. Pressure and Vacuum Gauges,
3. Electrical Tachometers,
4. Hook Gauge for water measurement,
5. Water Tank of about 45 m³ capacity. Such a tank can be used for testing pumps having capacities upto 11 m³/min.

Following measurements are taken :

1. Output of water
2. Total head
3. Power required
4. Efficiency.

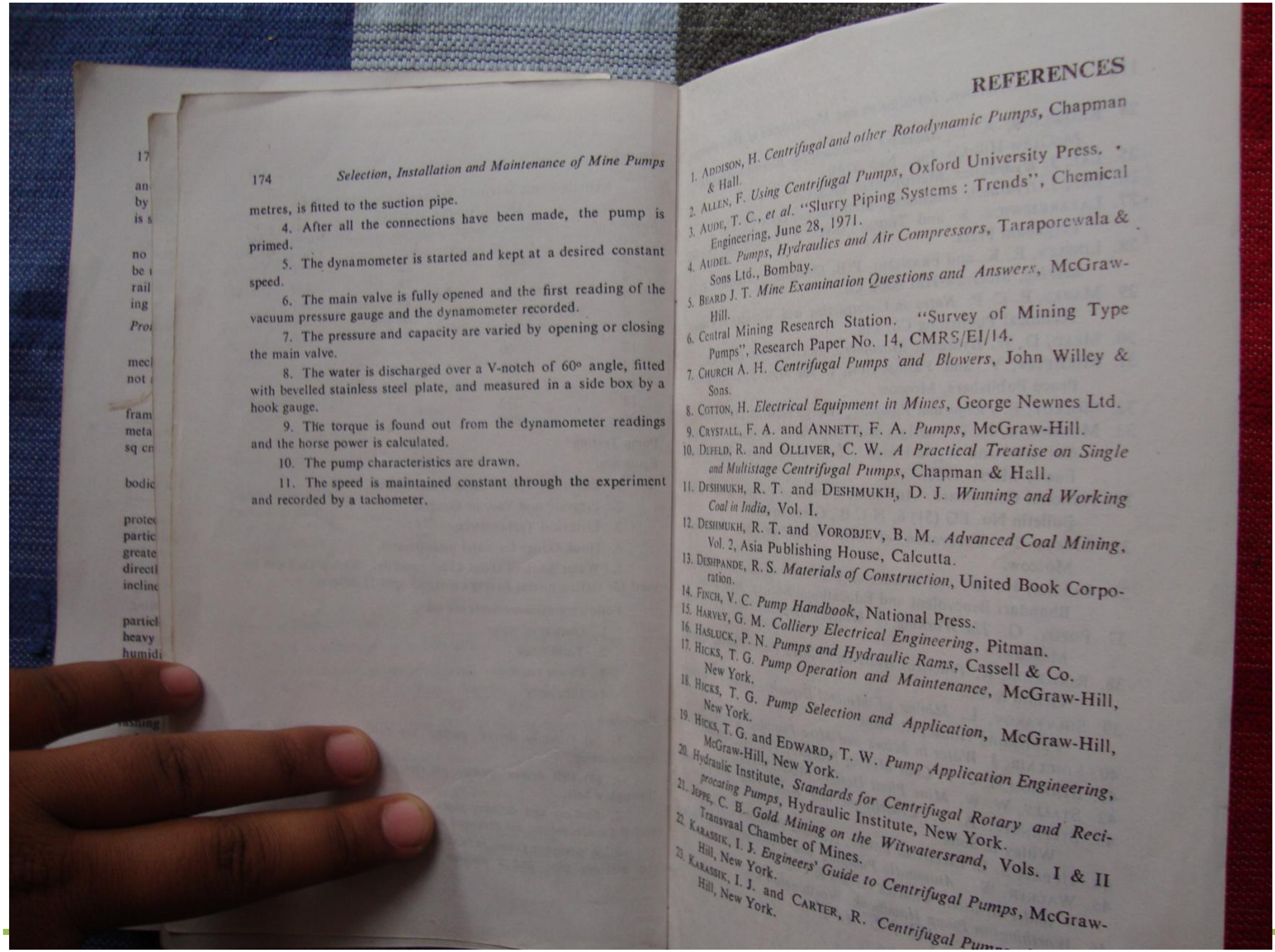
Procedure :

1. (*a*) Directly driven pumps are coupled directly to the dynamometer.

(*b*) Belt driven pumps are coupled to the dynamometer through a belt.

2. Suction and delivery pipes, with the necessary foot valve and the main valves, are arranged in position.

3. A pressure gauge, indicating the head in metres, is fitted to the delivery pipe and a vacuum gauge, showing suction lift in



metres, is fitted to the suction pipe.

4. After all the connections have been made, the pump is primed.

5. The dynamometer is started and kept at a desired constant speed.

6. The main valve is fully opened and the first reading of the vacuum pressure gauge and the dynamometer recorded.

7. The pressure and capacity are varied by opening or closing the main valve.

8. The water is discharged over a V-notch of 60° angle, fitted with bevelled stainless steel plate, and measured in a side box by a hook gauge.

9. The torque is found out from the dynamometer readings and the horse power is calculated.

10. The pump characteristics are drawn.

11. The speed is maintained constant through the experiment and recorded by a tachometer.

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